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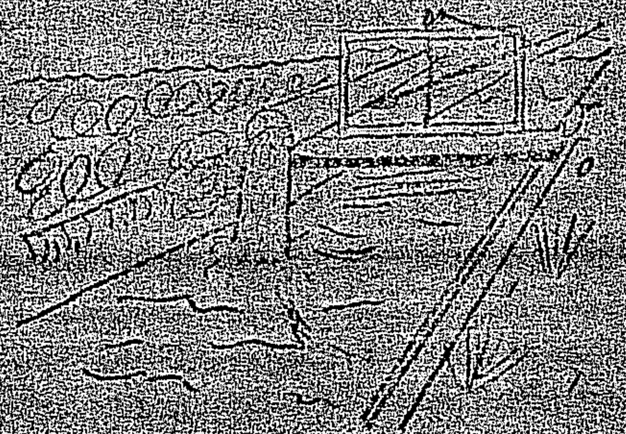
RECOVERY OF IRRIGATION SURFACE RUNOFF WATER



IMPERIAL COUNTY

Cooperative Agricultural Extension
University of California
Imperial County   Court House   El Centro
Circular 101

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Prepared by

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County Director - Farm Advisor

June 1977

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RECOVERY OF IRRIGATION SURFACE RUNOFF WATER

IN THE IMPERIAL VALLEY

Need for Recovery

Water running off the surface of the land serves no beneficial purpose. Water is a valuable natural resource and must be put to its maximum beneficial use. Surface runoff must be reduced to prevent a rise in the level of the Salton Sea.

Surface runoff control means savings to the grower by reducing water loss and loss of fertilizer that is applied with that water.

Methods of Reducing Runoff

The above listed problems can be eliminated or reduced by keeping the water on the land. Water may be kept on the land by careful irrigation, ponding at the lower end of the field, or by return flow systems.

Excessive ponding at the lower end of the field is damaging to most crop plants, and therefore, is not a desirable solution. Wherever practical, fields should be laid out to irrigate with a minimum runoff. However, to do an effective job of irrigating without tail water or excessive ponding, many fields would require extensive releveling.

Recovery of Runoff Water

Recovery of tail water can be accomplished by diverting water for reuse on fields below, by permanent pump back system, or by portable pump back system. Diverting tail water to lower fields has limited application without extensive releveling.

Permanent pump back systems do not appear practical at the present time because of high cost. Many growers are operating on leased land, and landlords are sometimes reluctant to spend the amount that a permanent system would cost. There is very little difference in the quality of surface run off water as compared to canal water. Field tests indicate there is very little change in quality on consecutive days with time of day. See Table 1.

Return flow systems will help to improve uniformity of water distribution, and reduce the irrigation labor required for checking run-through at lower ends of fields.

It should be realized, however, both by the irrigation foreman and irrigator that excessive amounts of water can end up in the field sump and delivery ditch if the head in the delivery ditch is not reduced about the second day of irrigating. Too much water through both systems could overload the delivery ditch.

Portable Pump-Back System

At the present time a portable return flow system appears most practical for Imperial Valley conditions. It costs less than the permanent system and can be moved to several fields during one season.

A portable system would consist of a pump mounted on a trailer and portable aluminum pipe for returning the water to the head end of the field. The system should be able to handle the surface runoff up to a maximum of 25 percent of the water order.

Data given in Table 2 gives the friction loss for 8-, 10- and 12-inch pipe for different lengths and discharges. Smaller lines would have excessive friction loss and require a higher lift pump and much larger horsepower engine, making them less economical.

The horsepower required to operate a pump can be computed from the following formula:

$$\text{H.P.} = \frac{\text{GPM} \times \text{Lift*(ft.)}}{3960 \times \text{Pump efficiency}}$$

Assuming discharge at 1350 GPM, the total lift 23 feet and the pump efficiency 0.67 (67 percent), the horsepower required would be:

$$\text{H.P.} = \frac{1350 \times 23}{3960 \times 0.67} = 11.7$$

* Total lift includes friction loss in the pipe, plus static head.

Layout of System and Costs

The tail water running off the lower ends of the furrows is collected in a sump located at the low point of the field. Experience in other areas has indicated that this runoff may amount to 25 percent of the total water applied at the head end of the field. The sump pump delivers the water through the pipeline back to the head end of the field where it is reused for irrigation.

The sketch in Figure 1 might be a typical layout for a 160-acre, 80-acre or 40-acre field. Typical costs are given in Table 2.

Table 1. Salinity of Irrigation Water and Tail Water (mmhos/cm)

Central Main Canal

Date	Delivery	Runoff
11/29/76	1.6	2.1
2/ 1/77	1.3	1.4
2/ 2/77	1.3	1.3
2/22/77	1.3	1.8
4/ 3/77	1.3	1.3
4/ 4/77	1.3	1.3

Malva Canal

Date	Delivery	Runoff
10/12/76	1.4	1.6
11/ 2/76	1.6	1.9
2/8/77	1.3	1.9
3/28/77	1.3	2.1
3/29/77	1.5	1.5

Narcissus Canal

Date	Delivery	Runoff
10/18/76	1.3	2.0

Olive Canal

Date	Delivery	Runoff
1/ 6/77	1.4	1.5
2/14/77	1.2	1.5
3/ 4/77	1.3	1.3
3/30/77	1.2	1.4

Pear Canal

Date	Delivery	Runoff
12/ 6/76	1.4	1.7
12/ 7/76	1.3	1.7
3/15/77	1.3	1.4
4/ 4/77	1.2	1.5

Rubber Canal

Date	Delivery	Runoff
12/17/76	1.3	1.9
3/ 3/77	1.3	1.8
3/28/77	1.2	1.9

Spruce Main Canal

Date	Delivery	Runoff
11/ 8/76	1.4	1.5
2/18/77	1.3	1.4
3/22/77	1.3	1.4
3/23/77	1.2	1.3

Trifolium Lateral 3 Canal

Date	Delivery	Runoff
12/13/76	1.3	1.3
2/10/77	1.4	1.4
Average of 29 locations	1.3	1.6

Table 2. Friction Loss Table, 8-, 10- and 12-inch Portable Aluminum Pipe

8" Diameter Pipe		Pipe Length	Friction Loss	
gpm	cfs	(Feet)	p.s.i.	Feet
600	1.34	100	0.38	0.9
		1320	5.01	11.6
		2640	10.02	23.1
1200	2.67	100	1.52	3.5
		1320	20.04	46.3
		2640	40.08	92.6
10" Diameter Pipe				
gpm	cfs			
600	1.34	100	0.12	0.3
		1320	1.52	3.5
		2640	3.05	7.0
1200	2.67	100	0.46	1.1
		1320	6.10	14.1
		2640	12.19	28.2
12" Diameter Pipe				
gpm	cfs			
600	1.34	100	0.04	0.1
		1320	0.58	1.3
		2640	1.15	2.7
1200	2.67	100	0.17	0.4
		1320	2.31	5.3
		2640	4.61	10.7

TABLE 3 - SUMMARY OF COSTS

TYPICAL IRRIGATION PUMP-BACK SYSTEMS

Based on a Berkeley Pump Model B6ZRM 1800 RPM with a Yan Mar 18 HP Diesel Engine, Installed on a trailer. A slope of 0.003 for farmers' field was assumed.

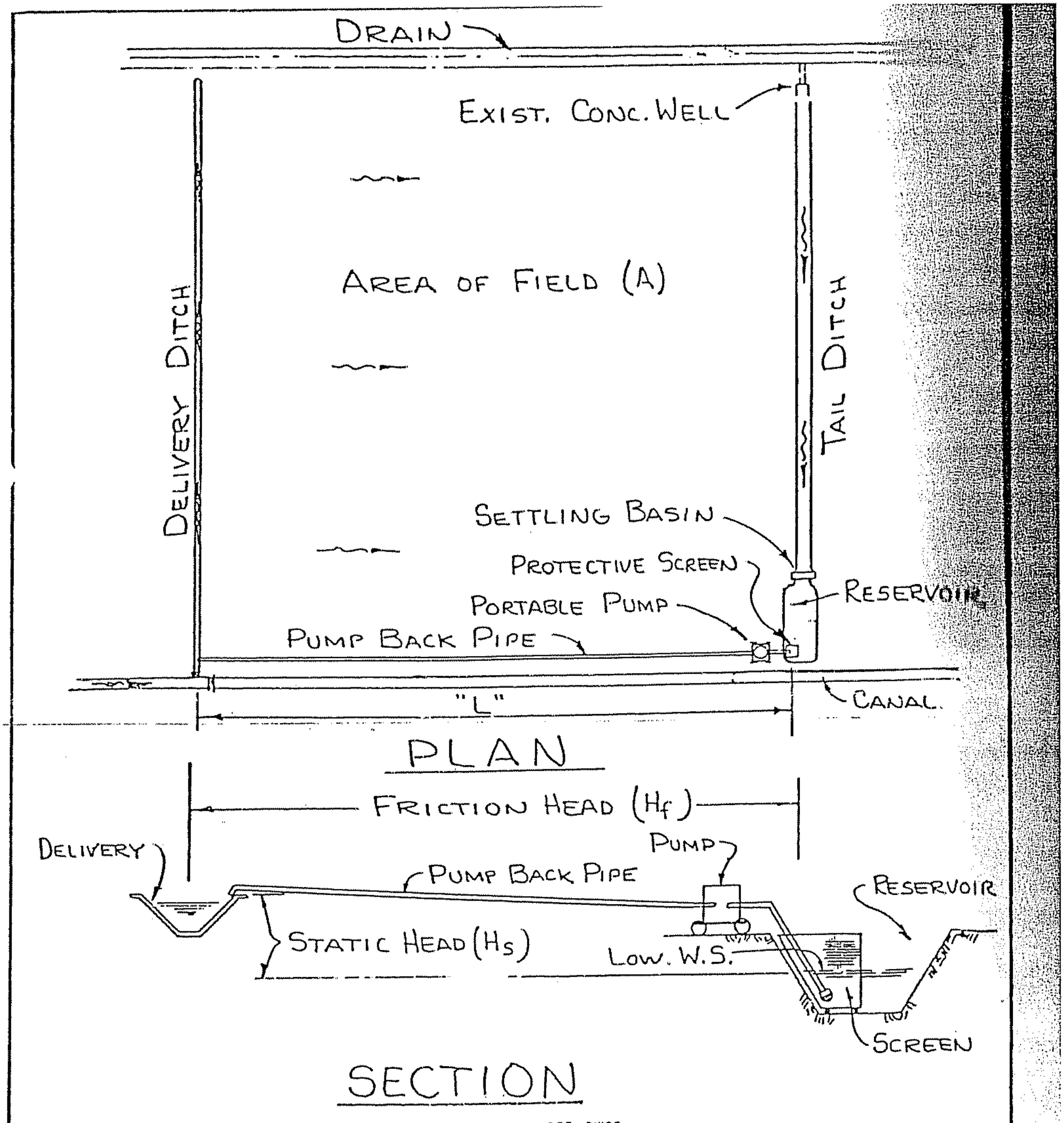
	Area of Field In Acres	Length of Pipe (Feet)	Aluminum Pressure Pipe (Inches)	Pump-Back Discharge (cfs)	Storage Reservoir (A.F.)	Static Head (Feet)	Friction Head (Feet)	Total Head (Feet)	Pump Efficiency (Percent)	Total Cost (Dollars)
1.	40 or 80	1,320	8	2 (900 gpm)	2	4	27	31	66	$11,000
2.	80 or 160	2,640	10	2½(1125 gpm)	2.5	8	25	33	70	16,000
3.	40 or 80	1,320	10	3 (1350 gpm)	3	4	19	23	67	13,200
4.	80 or 160	2,640	12	3½(1575 gpm)	3.5	8	24	32	68	17,600

COST BREAKDOWN:

	Cost of Pipe 0.064" Thick	Excavation @ $0.50/yd.^{3}	Protective Wire Mesh Screen	Pump and Engine* Mounted on Trailer	Appurtenances**	Total Cost
1.	$ 3,800	3,227 yd.^{3} = $1,600	$500	$3,900	$1,200	$11,000
2.	$ 8,400	4,032 yd.^{3} = $2,000	$500	$3,900	$1,200	$16,000
3.	$ 4,200	4,839 yd.^{3} = $2,400	$500	$3,900	$1,200	$12,200
4.	$ 9,200	5,645 yd.^{3} = $2,800	$500	$3,900	$1,200	$17,600

* Including suction hose and adaptors for pump to pipe.

** Including pipe trailer.



REF. DWGS.

IMPERIAL IRRIGATION DISTRICT
ENGINEERING SECTION
IMPERIAL, CALIFORNIA

TYPICAL IRRIGATION PUMP BACK SYSTEM

ISSUE 1: 4-5-77	DATE 4-5-77	SCALE NONE
ISSUE 2	DRAWN	CHECKED
ISSUE 3	APPROVED	

FIGURE 1

9-6

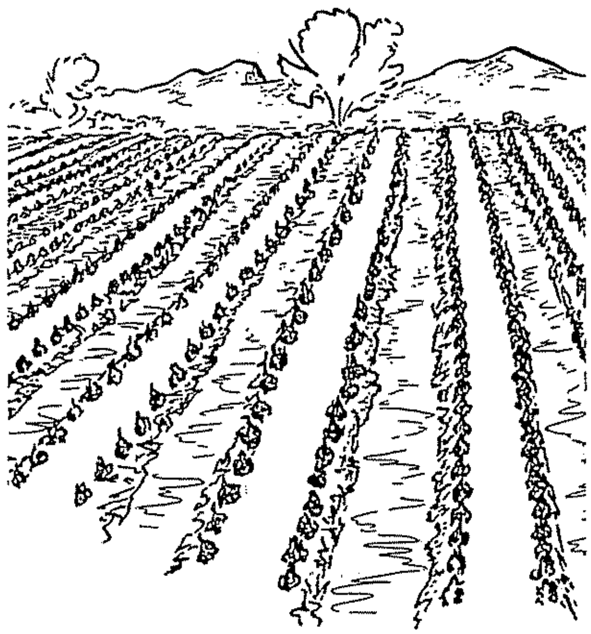
400 01

Irrigation

When?

How Much?

How?



YUMA COUNTY EXTENSION SERVICE
UNIVERSITY of ARIZONA
1047 FOURTH AVENUE
YUMA, ARIZONA

BULLETIN A-20

The University of Arizona

Cooperative Extension Service
And
Agricultural Experiment Station

12-17-68

Irrigation

WHEN?

HOW MUCH?

HOW?

Combine these guides and principles with your own judgment and experience. They will help you decide when to irrigate, how much to apply, and how to distribute the water evenly.

By Allan D. Halderman
Extension Agricultural Engineer
The University of Arizona

The University of Arizona
College of Agriculture
Cooperative Extension Service
George E. Hull, Director
Cooperative extension work in agriculture and home economics, The University of Arizona College of Agriculture and the United States Department of Agriculture cooperating. Distributed in furtherance of the Acts of Congress of May 8, and June 30, 1914.

10M—January 1962—Bulletin A-20

WHEN?

To decide when to irrigate, look at the plants and the soil. Both have signs which will help you. You must read the plant signs carefully because they will vary with the fertility and physical condition of the soil, the plant variety, and in some cases, disease infection.

Use all the plant and soil signs you can. Observe plants for wilting, color, growth rate, and stage of development. Check the soil for dryness or use a tensiometer as a guide.

Read the signs carefully and they will help answer your questions.

Read the Plant Signs!

Wilting

Wilting is a sign of the need for moisture. However, the yield potential of some plants has been reduced by the time wilting appears. Other plants often show wilt symptoms temporarily on hot afternoons even though they do not need an irrigation. Some diseases cause plants to wilt and appear as if they need water.

Color

Moisture stress is often reflected by the color of the leaves. With plenty of moisture, leaves light green color; when w needed a darker, bluish-gre pears. Color also is an indic plant variety and nitrogen so take these into account.

Growth Rate

When plants need wate grow slowly. You can see thi in cotton. Lack of new leaves blossoms to be exposed and "flower-garden" appearance

Another sign in cotton length of the green tip abc reddish color of the brancl than three or four inches in the plant is growing slowly. water may be the cause.

Stage of Developme

Lack of moisture affects more at some stages than Moisture stress during germ or pollination is especially ing.

Read the Soil Signs!

Available Moistur

Soil signs which indica amount of available moist maining depend on soil With an auger or probe, tak

Table 1. Soil Moisture Description When Irrigation is N

Soil Texture		
Coarse	Medium	Fine
Tends to stick together slightly but will not form a ball.*	Crumbly, but will form a ball.*	Pliable. Will f a ball.* Too di ribbon easily

* "Ball": formed by squeezing a handful of soil firmly.
** "Ribbon": formed between thumb and forefinger.

sample from a depth where most of the roots are located. Compare the samples with the descriptions given in Table 1. If they seem as dry, or dryer, it is time to irrigate.

Soil Moisture Tension

Plant roots must exert a suction force to remove moisture from soil particles. The amount of force can be measured with a tensiometer.

Install the tensiometer so the porous tip is in the active root zone. A second tensiometer, placed deeper at the same location, will tell you when irrigation water has penetrated to that depth.

Specific irrigation recommendations in terms of tensiometer readings and placement depths are available for some crops. Ask your County Agent for information about the crop you're growing.

In General

Weather, plant, and soil characteristics influence irrigation frequency as shown in Figure 1.

Figure 1. Influence of Weather, Plant, and Soil Characteristics on Irrigation Frequency

Irrigate Less Often	← Weather →		Irrigate More Often.
	Cool Damp Still Air	Hot Dry Windy	
	← Plants →		
	Deep Rooted Healthy Roots Incomplete ground cover	Shallow Rooted Damaged or Diseased Roots Complete ground cover	
	← Soil →		
	Deep Fine-textured	Shallow Coarse-textured	

HOW MUCH?

This depends on your reason for irrigating. If you want to germinate seed, soften a crust, cool the soil, or prevent frost damage, a very light irrigation is enough.

If you want to leach salts out of the soil or provide moisture for plant growth, a heavier irrigation is needed.

To Leach Salts

Leach salts out of your soil with a heavy irrigation. The extra water carries salts downward out of the root zone as shown in Figure 2. The amount of water needed depends on the amount of salt, soil porosity, and the crop to be grown.

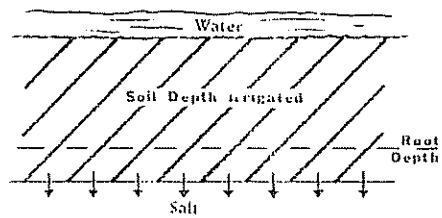


Figure 2. Leaching Salts out of Root Zone

To Provide Moisture For Plants

If you irrigate a growing crop at the time it needs water, use Table 2 to estimate the acre-inches per acre you must deliver to the field. Use more water if the plant and soil signs indicate irrigation is over-due.

For greater accuracy, use ar er to take samples of soil from foot of the root zone. Look ir ure 3 for the description tha each sample. Find the corres ing moisture deficiency on side. (See pages 8 and 9).

Tabulate the results. Add tc er the inches needed for eacl of soil in the rooting zone c crop to estimate the inches of needed.

Increase the total about one to allow for losses.

EXAMPLE:

DEPTH (IN FEET)	TEXTURE	DESCRIPTION	INCH WATER
0-1	Loam	Small clods Crumble easily	
1-2	Loam	Forms a weak ball	
2-3	Loam	Forms a weak ball	
3-4	Sandy Loam	Forms a weak ball	
4-5	Sandy Loam	Makes a good ball	
5-6	Sandy Loam	Makes a good ball	
		Inches Needed in the Soil	

Add 2.1 inches to allow for losses.
Total water needed: 8.0 acre-inches pe

To find the total acre-i needed for various lengths o and border widths, use Table furrow irrigation, use Table

Table 2. Delivery Requirements in Acre-Inches per Acre for Various So Textures and Plant Root Depths*.

Root Depth of Plants**	Soil Texture: Sandy	Medium	Fine
2 feet	2-3	3-4	4-5
4 feet	4-6	6-8	7-9
6 feet	6-9	9-12	10-13

* Based on 50% to 65% depletion of available moisture from the root zone 60% application efficiency. For higher application efficiencies, decreas delivery requirement accordingly.

** To wet the soil to half the depth of the root zone, apply about 3/4 of the shown.

Table 3. Total Acre-Inches Needed per Border for Various Border Lengths and Widths With Different Delivery Requirements. (To the nearest one-half acre-inch).

Length (feet)	Width (feet)	Delivery Requirement (Acre-inches per acre from Table 2)					
		2	4	6	8	10	12
660	30	1.0	2.0	2.5	3.5	4.5	5.5
	40	1.0	2.5	3.5	5.0	6.0	7.5
	50	1.5	3.0	4.5	6.0	7.5	9.0
	75	2.5	4.5	7.0	9.0	11.5	13.5
	100	3.0	6.0	9.0	12.0	15.0	18.0
880	30	1.0	2.5	3.5	5.0	6.0	7.5
	40	1.5	3.0	5.0	6.5	8.0	9.5
	50	2.0	4.0	6.0	8.0	10.0	12.0
	75	3.0	6.0	9.0	12.0	15.0	18.0
	100	4.0	8.0	12.0	16.0	20.0	24.0
1320	30	2.0	3.5	5.5	7.5	9.0	11.0
	40	2.5	5.0	7.5	9.5	12.0	14.5
	50	3.0	6.0	9.0	12.0	15.0	18.0
	75	4.5	9.0	13.5	18.0	22.5	27.5
	100	6.0	12.0	18.0	24.0	30.5	36.5
2640	30	3.5	7.5	11.0	14.5	18.0	22.0
	40	5.0	9.5	14.5	19.5	24.0	29.0
	50	6.0	12.0	18.0	24.0	30.5	36.5
	75	9.0	18.0	27.5	36.5	45.5	54.5
	100	12.0	24.0	36.5	48.5	60.5	72.5

Table 4. Total Acre-Inches Needed per Set for Various Furrow Lengths, Numbers of Furrows, and Delivery Requirements (To the nearest one acre-inch).

Length (feet)	Number of 40-inch furrows	Delivery Requirement (Acre-inches per acre from Table 2)					
		2	4	6	8	10	12
660	50	5	10	15	20	25	30
	100	10	20	30	40	50	61
	150	15	30	45	61	76	91
	200	20	40	61	81	101	121
880	50	7	13	20	27	34	40
	100	13	27	40	54	67	81
	150	20	40	61	81	101	121
	200	27	54	81	108	135	162
1320	50	10	20	30	40	50	61
	100	20	40	61	81	101	121
	150	30	61	91	121	151	182
	200	40	81	121	162	202	242
2640	50	20	40	61	81	101	121
	100	40	81	121	162	202	242
	150	61	121	182	242	303	364
	200	81	162	242	323	404	485

You can find the acre-inches delivered by different stream siz
time of set combinations in Table 5.

Table 5. Acre-Inches Delivered by Streams of Various Sizes in Different Time P

Stream Size			Time (hours)							
CFS*	GPM**	MI***	2	4	6	8	12	16	20	24
1.0	450	40	2	4	6	8	12	16	20	24
1.5	675	60	3	6	9	12	18	24	30	36
2.0	900	80	4	8	12	16	24	32	40	48
2.5	1125	100	5	10	15	20	30	40	50	60
3.0	1350	120	6	12	18	24	36	48	60	72
3.5	1575	140	7	14	21	28	42	56	70	84
4.0	1800	160	8	16	24	32	48	64	80	96
4.5	2025	180	9	18	27	36	54	72	90	108
5.0	2250	200	10	20	30	40	60	80	100	120
6.0	2700	240	12	24	36	48	72	96	120	144
7.0	3150	280	14	28	42	56	84	112	140	168
8.0	3600	320	16	32	48	64	96	128	160	192
9.0	4050	360	18	36	54	72	108	144	180	216
10.0	4500	400	20	40	60	80	120	160	200	240
12.0	5400	480	24	48	72	96	144	192	240	288
14.0	6300	560	28	56	84	112	168	224	280	336
16.0	7200	640	32	64	96	128	192	256	320	384

* Cubic feet per second.
** Gallons per minute.
*** Arizona Miner's Inches

Many soils take water more slowly as the season progresses. During late June, July, and August, you may find it impractical to completely refill the soil to the depth of the roots. Store deep moisture with a pre-planting irrigation during the time the soil takes water more
idly.

Young plants grown on
must be irrigated until moistur
moved into the bed even th
this often results in losses by
seepage.

For sprinkler irrigation, esti

(Continued on page 10)

Figure 3. Soil Moisture and Appearance Chart*

SOIL TEXTURE CLASSIFICATION

Moisture deficiency in./ft.	Coarse (loamy sand)	Light (sandy loam)	Medium (loam)	Fine (clay loam)	Moistu deficien in./ft.
0.0	(field capacity) Leaves wet outline on hand when squeezed.	(field capacity) Leaves wet outline on hand; makes a short ribbon.	(field capacity) Leaves a wet outline on hand; will ribbon out about one inch.	(field capacity) Leaves slight moisture on hand when squeezed; will ribbon out about two inches.	0.0
0.2					0.2
0.4	Appears moist; makes a weak ball. Appears slightly moist. Sticks together slightly.	Makes a hard ball.	Forms a plastic ball; slicks when rubbed.	Will slick and ribbon easily.	0.4
0.6	Very dry, loose; flows through fingers. (Wilting point)	Makes a good ball.	Forms a hard ball.	Will make a thick ribbon; may slick when rubbed.	0.6
0.8		Makes a weak ball.	Forms a good ball.	Makes a good ball.	0.8
1.0		Will not ball.			1.0
1.2		Wilting point.	Forms a weak ball.	Will ball, small clods will flatten out rather than crumble	1.2
1.4			Small clods crumble fairly easily.	Clods crumble.	1.4
1.6					1.6
1.8			Small clods are hard (wilting point)		1.8
2.0				Clods are hard, cracked. (wilting point)	2.0

* Adapted from "Field Method of Approximating Soil Moisture for Irrigation," by John L. Merriam, Transactions of the A.S.A.E., Vol. 3, No. 1, 1960.

the acre-inches needed per acre from Table 2 or Figure 3. Divide by the application rate in inches per hour to find the time of set.

Use a soil tube or probe a few days after an irrigation to see if moisture penetrated to the desired depth.

HOW?

Distribute Evenly

Delivering the correct amount of water is not enough; you must distribute it evenly.

System design is important for either sprinkler or surface irrigation. A well-designed sprinkler system assures relatively even distribution without an experienced irrigator. For surface irrigation, even distribution depends on system design and the skill of the irrigator.

To evaluate your surface irrigation, compare the total time water is on the soil at several different places down the border or furrow. You can do this by observing the time when water reaches each place and when it has all seeped into the soil.

For distribution to be even, the elapsed times must be approximately equal. This assumes all the field takes water at the same rate. If your soil is not uniform, try to keep hard spots under water longer than sandy streaks.

You may be able to get even distribution by adjusting the stream size and width of border or number of furrows. If not, consider a change in the length of run or slope, or both.

Use large streams for flat slopes, long runs, light irrigations and soils which take water rapidly.

Use small streams for steep slopes, short runs, heavy irrigations, and soils which take water slowly.

To Border Irrigate

Choose a combination of stream size and border width so the upper end is irrigated by the time the advancing stream approaches the lower end. At that time, move the water to the next border. The water in the first border will continue to move down the slope and complete the irrigation as shown in Figure 4.

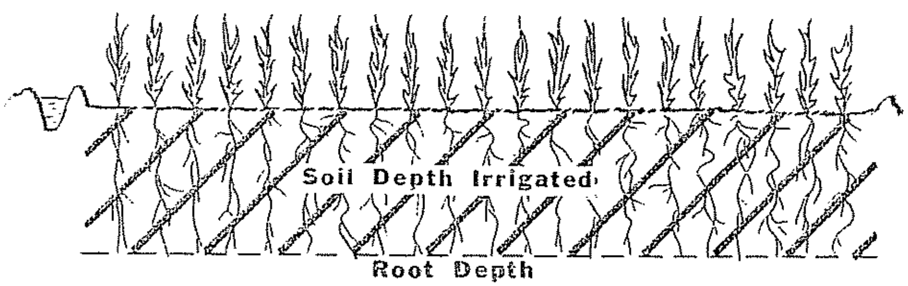


Figure 4. Correct Amount of Water, Evenly Distributed

On soils which take water slowly, moisture may not have penetrated very deeply at the upper end when the stream reaches the lower end. If you shut the water off at th none of the field will be i adequately. As shown in F plant growth will be limite

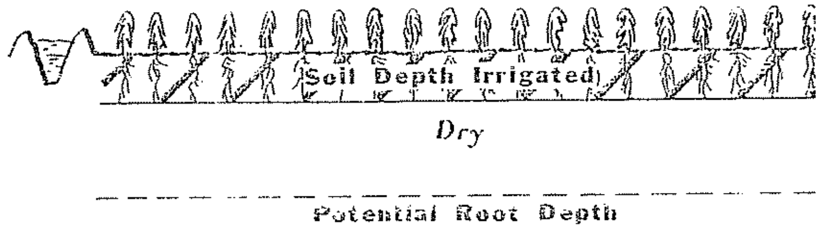


Figure 5. Water Evenly Distributed, But Not Enou

In an effort to obtain penetration, you may let the stream continue. This will cause greater penetration at the lower end. Excessive or run-off may occur. (See

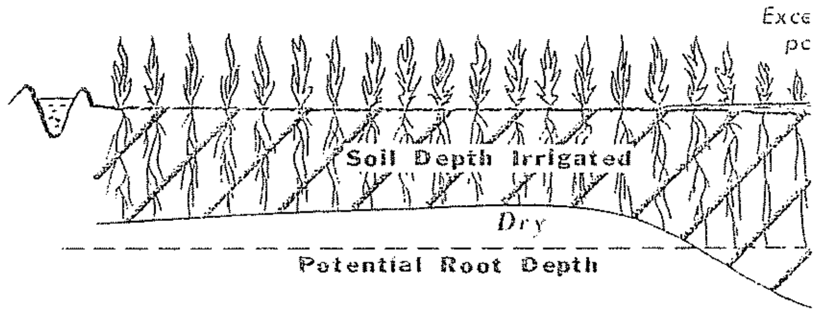


Figure 6. Excessive Ponding

Another way is to reduce the stream size when it approaches the end of the run and let it continue as long as necessary. In t you can reduce the amount ing or run-off.

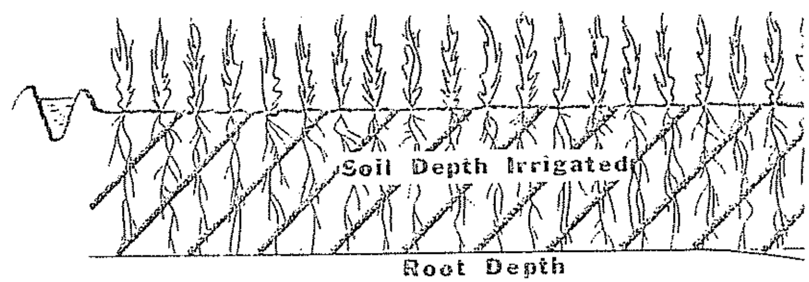


Figure 7. Correct Amount of Water, Nearly Uniform Distribution (Reduced Stream)

A smaller stream or wider border will tend to help.

If you still have trouble getting adequate penetration at the upper end without excessive ponding or run-off at the lower end, consider grading to a flatter slope.

On soils which take water rapidly, you are likely to have deep seepage losses at the upper end or too shallow an irrigation at the lower end. Figure 8 illustrates this condition.

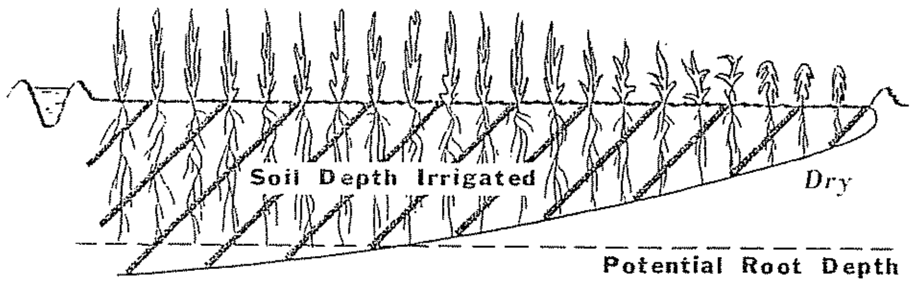


Figure 8. Too Deep at Upper End or Too Shallow at Lower End

You can partly correct this by letting the stream continue after it has reached the end of the border. Water ponds and moves downward into the root zone at the lower end. Notice from Figure 9 (Below) that a "Four-Fifths Zone" is likely to persist.

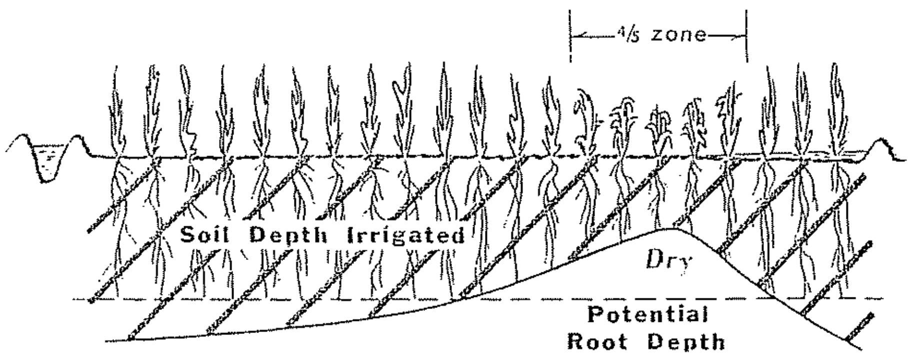


Figure 9. "Four-Fifths Zone"

In this case, try a larger stream or a narrower border. If that doesn't help, consider shortening the length of run.

To Furrow Irrigate

Slope has an important influence on selection of the procedure used to achieve even distribution. The best way is the one which keeps water on all parts of your field for equal periods of time.

Very Flat Slopes

On very flat slopes, water in furrows responds very much as it does in borders. You may be able to use a constant stream size and get even distribution. Follow the guides outlined for border irrigation.

Steep Slopes

Estimate the time water must be on the soil to provide the desired penetration. Try several non-erosive furrow stream sizes. Choose one which reaches the end of the furrow in one-fourth the estimated time or less. Change the set when water has been on the lower end for the required time.

For example, if water must be on the soil for 20 hours to p penetration to the bottom root zone, the stream should the end of the furrow in 5 ho less. The total set would hours.

To avoid excessive pondi run-off, reduce the stream when the water reaches the the furrow. If you don't want this, you may prefer to use water or pump-back system.

The purpose of the "one-f rule is to get even distri down the entire furrow. Th a tendency for water to be upper end longer than on the By using a large stream at fir can make the times more equal. By reducing the strea when it reaches the end, y avoid excessive ponding or r Figure 10 shows the result.

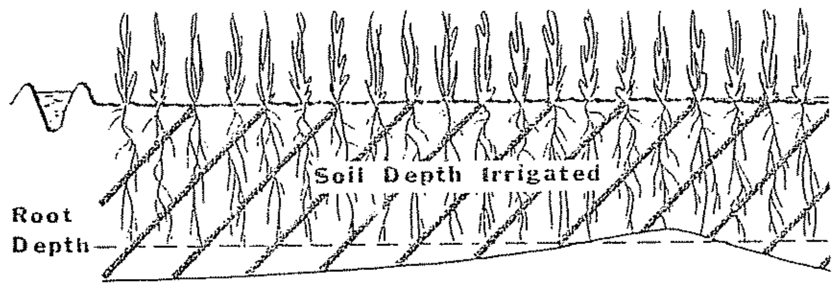


Figure 10. Correct Amount Nearly Evenly Distributed (Reduced Furrow Stream)

Moderate Slopes

Follow a procedure between the extremes used for very flat slopes and for steep slopes. Choose an initial stream which advances to the end of the furrow in less than the irrigating time required. For example, distribution may be acc if the initial stream advances end of the furrow in one-h time required for the desire tration.

Reduce the stream size v reaches the end of the fur avoid excessive ponding or run-off. If you prefer, use a tail-water or pump-back system.

On soils which take water slowly, you'll need a small stream for a long time. Figure 11 shows what can happen if the time is too short and the stream too large. The only adequate penetration may be where water was ponded. Too much water will cause excessive ponding or run-off.

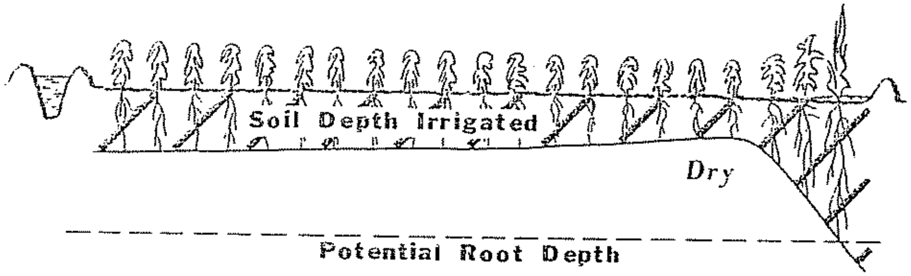


Figure 11. Poor Penetration Except in Ponded Area

Where tractor wheels have compacted the bottom of the furrow, a small stream will seep into the soil very slowly as indicated in Figure 12.

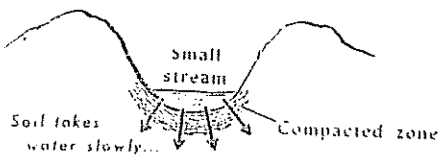


Figure 12. Small Stream, Compacted Furrow, Steep Slope

Consider grading the field to a flatter slope. This will cause the water to rise higher in the furrow and seep into the soil faster as shown in Figure 13.

Figure 13. Small Stream, Compacted Furrow, Flat Slope

If your soil takes water rapidly, you'll need as large a stream as possible at first. Size of the maximum stream will be limited by erosion on steep slopes. On flat slopes, it will be limited by furrow capacity.

If the run is too long, you will tend to over-irrigate at the upper end and under-irrigate at the lower end. If you pond water at the lower end, you are still likely to have a

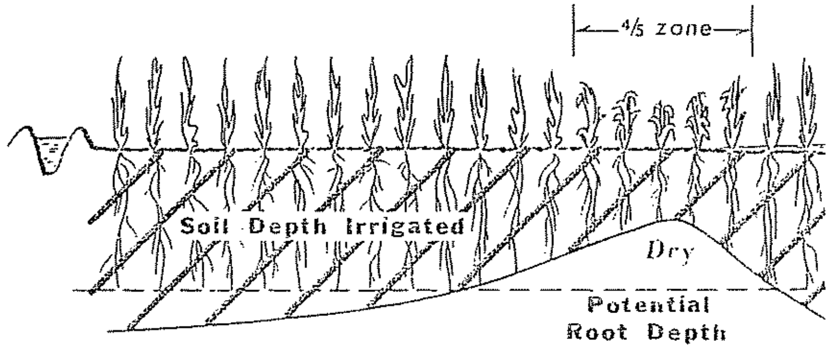


Figure 14. Too Long a Run

"four-fifths zone" develop where there isn't enough soil moisture.

To Basin Irrigate

To irrigate a basin with no fall in any direction, use as large a stream as possible without causing erosion. Water should cover the entire area in no longer than one-fourth the time it stands on the field. If it doesn't, consider making the basin smaller.

To Irrigate With Corrugations

Use the same guides for co
tion irrigation as for furrow

Space corrugations so wat
move into the areas between
gations in about the time it p
tes to the desired depth. I
you will need a wide spaci
fine-textured soils and a clos
ing for sandy soils (see Figu

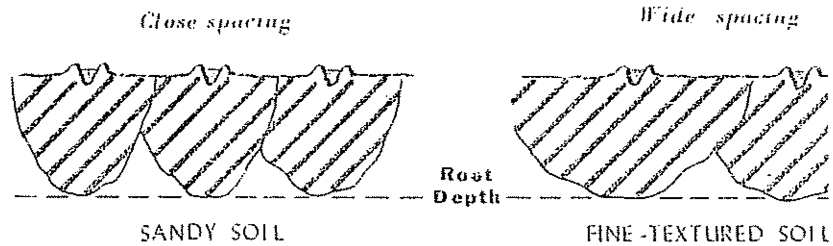


Figure 15. Corrugation Spacing

A few days after irrigation, use a soil probe or auger to determine how evenly water has penetr different parts of the field.

You may be limited in **WHEN, HOW MUCH,** and **HOW** you irrigate. Even so, the first step is to know what is best and come as close to this as possible.

Use these principles and guides as the basis for your decisions:

WHEN? Read the Plant and Soil Signs.

HOW MUCH? Apply according to the soil moisture deficiency in the root zone.

HOW? Use any procedure which permits even distribution of water. You can check this by comparing the time water is on the soil at different places in the border or furrow.

This publication is issued by The Cooperative Extension Service and The Agricultural Experiment Station of The University of Arizona. See your local County Extension Agent for additional information.

9-7

MOORE/1h/339-9269

March 9, 1989

IIDWD-ID

WD Seal

Bill Stevens and Associates
112 East Washington
Phoenix, AZ 85034

Attention: Bill Allen

Dear Bill:

Enclosed you will find the information you requested regarding water consumption on alfalfa. The fields in the survey represented a wide cross section of Imperial Valley soil types.

I hope you will find this information helpful.

Yours truly,

Eldon L. Moore

ELDON L. MOORE
Superintendent, Asst. General
Irrigation and Drainage

Enclosure

MFF: IID-300C - Water Duty Report - Data for Growing Season, Imperial Division; Period 1988, dated March 3, 1989.

ALFALFA/2

ALFALFA CROP Flat bordered lands.
No pump back.

DIVISION IMPERIAL

PERIOD 1988

ACCOUNT NUMBER	OWNER OR TENANT	CANAL	GATE	DATE OF FIRST IRRIGATION	DATE OF PLANTING	DATE OF LAST IRRIGATION	DATE OF HARVEST	ACREAGE GROSS	ACREAGE NET	TOTAL ACRE FEET DELIVERED	ACRE FEET PER ACRE NET CROP
8434-002	Golden State Farms	Newside	29A	02-11-88	01-01-88	11-08-88		79	65	551.00	8.48
8334-003	Golden State Farms	Newside	30	02-13-88	01-01-88	11-10-88		80	70	375.40	5.36
0052-002	James Adam	Dahlia	76	02-29-88	01-06-88	11-21-88		75	68	428.00	6.29
	Valley Property	Trif. 3	43	01-07-88		09-20-88	Various	160	150	712.4	4.75
	Robert Monte	Thorn	39	01-17-88		12-29-88	Various	80	72	519.0	7.21
	James Walker	T7	136	01-22-88		11-25-88	Various	80	75	519.2	6.92
1324-015	John Chimits	Pepper	4	02-25-88	10-22-87	12-27-88		148	139	908.8	6.53
7971-002	R.S. Garewal & Sons	Pomelo	3-A	01-22-88	02-18-86	12-23-88		71	68	445.6	6.55
8165-007	Larry Smith	South Alamo	29	01-02-88	11-15-86	12-07-88		128	101	937.6	9.28
8165-008	Larry Smith	Ash	124	02-02-88	09-30-86	11-26-88		39	35	266.5	7.61

DATE March 3, 1989

DIVISION SUPERINTENDENT Eldon L Moore
B. L. HALE ASST. SUPRT.

ALFALFA CROP Corrugated with no pump back.

DIVISION IMPERIAL

PERIOD 1988

ACCOUNT NUMBER	OWNER OR TENANT	CANAL	GATE	DATE OF FIRST IRRIGATION	DATE OF PLANTING	DATE OF LAST IRRIGATION	DATE OF HARVEST	ACREAGE		TOTAL ACRE FEET DELIVERED	ACRE FEET PER ACRE NET CROP
								GROSS	NET		
5538-004	Camilo Preciado	Dahlia	61	02-15-88	01-06-88	12-29-88		40	38	287.40	7.56
6337-023	James Shipman	Eucalyptus	122	01-23-88	01-01-88	12-11-88		154	144	986.80	6.53

DATE March 3, 1989

DIVISION SUPERINTENDENT Elden L Moore

B. L. HALE ASST. SUPRT.

ALFALFA CROP Corrugated with pump back. DIVISION IMPERIAL PERIOD 1988

ACCOUNT NUMBER	OWNER OR TENANT	CANAL	GATE	DATE OF FIRST IRRIGATION	DATE OF PLANTING	DATE OF LAST IRRIGATION	DATE OF HARVEST	ACREAGE GROSS	ACREAGE NET	TOTAL ACRE FEET DELIVERED	ACRE FEET PER ACRE NET CROP
3592-005	John Veysey Farms	Newside	33	02-20-88	01-08-88	12-06-88		153	140	814.60	5.82
3592-003	John Veysey Farms	Newside	30A	02-19-88	01-08-88	12-04-88		153	143	979.60	6.85

DATE March 3, 1989

EM DIVISION SUPERINTENDENT Eldon L. Moan
B. L. HALE ASST. SUPRT.

9-8

4CC.C1

IID-353

IMPERIAL IRRIGATION DISTRICT
MEMORANDUM

TO	J. Silva	DATE	February 15, 1989
		FROM	Douglas Welch
COPIES	R. Lang K. Holdsworth	DEPARTMENT	Water
		SUBJECT	Underground Drip Irrigation System

As requested, following are my comments on the attached paper entitled "Commercial Production of Field and Vegetable Crops with Subsurface Drip Irrigation." I have also included some general comments on drip systems.

On page 1, paragraph 4, the subject is sugar beets and Table 1 is referred to, but sugar beets are not included in Table 1.

The units for the data in Column 1 of Table 1 are Kg./acre not Kg./Ha.

The cost of the system, $3,185/Ha., on page 3, paragraph 5, does not agree with the cost of the system, $4,446/Ha., on page 7, Table 4. Interest may be included in the cost of the system in Table 7.

Water application on furrow irrigated cotton in Table 1 is 65 inches and with drip it is 32 inches. Typical applied water on furrow-cotton in IID is between 40 and 50 inches.

GENERAL COMMENTS ON DRIP VS. FLAT IRRIGATION.

Many have touted drip irrigation as the "answer" to improving irrigation efficiency and reaping very large increases in production. Drip irrigation is not necessarily the best system for all situations. The type of irrigation system that is best suited to a field depends on the field's soil type, field slope, soil salinity, delivery-water quality, management skills, cropping rotation, etc. While it may be true that higher production with less water can be achieved on many crops with drip irrigation, it is also true that the increase in yields does not necessarily justify the cost to convert to drip.

One major problem with typical comparisons between drip and flat irrigation is that the drip system is assumed to be managed very well while the flat irrigation is not. If the management of the flat irrigation was comparable to drip, the production and water requirements would be more competitive. With the exception of

W

RJ

truck crops, the net income from many crops that are flat irrigated in IID can be much better than can be achieved with drip irrigation. Many fields in the District have been laser leveled, the length of run has been shortened, and the system is being managed properly to achieve high production and irrigation efficiencies higher than 85 percent.

The key features of subsurface drip are:

- uniform application controlled by design
- emitters are placed close to the roots
- timely application of water and nutrients
- buried tubing does not interfere with cultural activities
- reduced amount of water required
- high capital cost

What are some of the problems that might be associated with drip irrigation?

- Will the soil salinity increase with drip irrigation?
- Will supplemental leaching, that is required to reduce any increases in salinity, offset reduced water use during the growing season?
- Farmers will probably need to build ponds so that they can shut the system off.
- What are the alternatives to drip?
    - surge irrigation
    - LEPA
    - level furrow
    - level basin
    - tailwater recycling
    - sprinklers
    - cut-back

The potential for conserving water with drip systems should be evaluated. Although it may only be applicable to a small portion of the IID it could prove to be a viable alternative.

Douglas G. Welch, Jr.

ccm

9-9

400.01

Moore/lh/339-9265

IIDWD

April 1, 1988

WD sec

Mr. Charles Goodman
Research Associate
Dept. of Agriculture & Res. Econ.
207 Giannini Hall
University of California
Berkeley, CA 94720

Dear Mr. Goodman:

This is in response to your letter of March 21, 1988 requesting information regarding water use and cost within the Imperial Irrigation District.

The cost of water in 1985 and 1986 was $9.00 per acre foot. In 1985, 2,335,297 acre-feet were delivered to the water users; in 1986 there were 2,336,583 acre-feet delivered.

The following is a list of the major crops that are grown in the Imperial Valley and the average water used per acre:

Crop	AF/AC	Crop	AF/AC
Alfalfa	6.30	Melons	2.30
Asparagus	6.26	Lettuce	1.71
Sugar Beets	3.61	Carrots	2.40
Cotton	3.48	Tomatoes	2.30
Rye	3.00	Cauliflower	1.60
Wheat	2.16	Cabbage	2.29
Onions	5.25	Broccoli	1.90
Bermuda	7.67	Misc. Garden Crops	1.70
Sudan	3.21	Misc. Permanent Crops	4.20

We trust this is satisfactory to your needs.

Yours very truly,

Charles L. Shreves

CHARLES L. SHREVES
General Manager

GOODMAN

IID ROUTING SLIP	NOT TO BE USED FOR APPROVALS, DISAPPROVALS, CONCURRENCES OF SIMILAR ACTIONS

	TO	INIT.	DATE
GM	GENERAL MANAGER		
AGM	ASSISTANT TO GENERAL MANAGER		
WD	MANAGER, WATER DEPARTMENT		
PD	MANAGER, POWER DEPARTMENT		
OP	MANAGER, OPERATIONS SERVICES		
FA	MANAGER, FINANCE & ACCOUNTING		
PE	MANAGER, PERSONNEL DEPARTMENT		
PI	DIRECTOR, PUBLIC INFORMATION		
TR	TREASURER		
SC	SECRETARY, BOARD OF DIRECTORS		
GF	GENERAL FILES		
LE	LEGAL COUNSEL		
SA	SAFETY		
AU	AUDITOR		
RE	REAL ESTATE		
SCI	SECURITY, CLAIMS, INVESTIGATIONS		
A	Underwood		
	Moore		

[X] ACTION [ ] INFORMATION

SUBJECT: Univ. of CA - Berkeley let. dtd. 3-21-88 requesting crop water use + cost

SUSPENSE: 4-5-88

ACTION REQUIRED:

X	PREPARE REPLY FOR SIGNATURE OF GENERAL MANAGER
	PREPARE REPLY FOR SIGNATURE OF PRESIDENT, BOARD OF DIRECTORS
	REPLY DIRECT: FURNISH COPY TO GENERAL MANAGER
	OTHER ACTION (SEE REMARKS)

REMARKS:

Route thru Mr. Wheeler

I have return envelope

Chaw

CHECK ACTION DISIRED

I	INFORMATION		SIGNATURE		NOTE AND RETURN
	CIRCULATE	A	NECESSARY ACTION		SEE ME

FROM	TELEPHONE	DATE
IMPERIAL IRRIGATION DISTRICT OPERATING HEADQUARTERS	339-9220	3-25-88

IID ROUTING SLIP	NOT TO BE USED FOR APPROVALS, DISAPPROVALS, CONCURRENCES OF SIMILAR ACTIONS	

		TO	INIT.	DATE
I	GM	GENERAL MANAGER	JA	3/24
I	AGM	ASSISTANT TO GENERAL MANAGER		
A	WD	MANAGER, WATER DEPARTMENT		
	PD	MANAGER, POWER DEPARTMENT		
	OP	MANAGER, OPERATIONS SERVICES		
	FA	MANAGER, FINANCE & ACCOUNTING		
	PE	MANAGER, PERSONNEL DEPARTMENT		
	PI	DIRECTOR, PUBLIC INFORMATION		
	TR	TREASURER		
	SC	SECRETARY, BOARD OF DIRECTORS		
	GF	GENERAL FILES		
	LE	LEGAL COUNSEL		
	SA	SAFETY		
	AU	AUDITOR		
	RE	REAL ESTATE		
	SCI	SECURITY, CLAIMS, INVESTIGATIONS		

[X] ACTION [ ] INFORMATION

SUBJECT: Univ of CA.-Berkeley let dtd 3-21-88 requesting crop water use & cost

SUSPENSE: 4-8-88

ACTION REQUIRED:

X	PREPARE REPLY FOR SIGNATURE OF GENERAL MANAGER
	PREPARE REPLY FOR SIGNATURE OF PRESIDENT, BOARD OF DIRECTORS
	REPLY DIRECT: FURNISH COPY TO GENERAL MANAGER
	OTHER ACTION (SEE REMARKS)

REMARKS:

CHECK ACTION DISIRED

I	INFORMATION		SIGNATURE		NOTE AND RETURN
	CIRCULATE	A	NECESSARY ACTION		SEE ME

FROM	TELEPHONE	DATE
IMPERIAL IRRIGATION DISTRICT OPERATING HEADQUARTERS	339-9220	3-24-88

UNIVERSITY OF CALIFORNIA SYSTEMWIDE ADMINISTRATION

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS

Office of the Director
211 Giannini Hall
Berkeley, California 94720

March 21, 1988

Library
248 Giannini Hall
Berkeley, California 94720

Mr. Charles L. Shreves, Manager
Imperial Irrigation District
1284 Main Street
P.O. Box 1809
El Centro, Calif. 92244

Dear Mr. Shreves:

This is to request information regarding crop water use and cost within the Imperial Irrigation District. This information is needed for a research project we're conducting under the auspices of the Giannini Foundation.

For calendar years 1985 and 1986, the following data is needed:

1. Total surface water delivered to the farm gate.
2. Farm gate retail price of surface water.
3. Acreage and unit applied water (acre-feet/acre) for each crop.

We are grateful for your help in providing this information.

Sincerely,

Charles Goodman
Research Associate
Dept. of Agric. & Res. Econ.
207 Giannini Hall
University of California
Berkeley, Calif. 94720
(415) 642-6180, -3345

9-10

Knell/ga/339-9393

IIDWD-WC

March 26, 1987

Mr. Mark Arnold
Fifield Land and Cattle Co.
4307 Fifield Road
Brawley, CA 92227

Dear Mr. Arnold:

At your meeting of March 11th with Mr. Steve Knell, Agricultural Engineer of the Water Conservation Unit, you asked some questions that we now have answers for.

1. Enclosed are the latest Crop Coefficients (Kc) released by the University of California.

2. The infra-Red Gun used by the District belongs to the Bureau of Reclamation and is not available for public use.

3. As a possible source of flow gages for use with the broad-crested weirs in your ditches, call Bill Crawford at 922-6804 in Blythe. I've been told he can make some up for you.

4. I feel that scheduling on six fields for one individual is sufficient. However, if additional fields are desired I might suggest dropping either Narcissus 16 and 16-A or Mayflower 20 and 20-A. These fields are generally irrigated at the same time so scheduling for one combination should satisfy the needs of the other. By dropping two fields we would be able to pick up some fields in the Trifolium area. Let me know what you think.

If you have additional questions or if we can be of further service please don't hesitate to call.

Yours very truly,

Douglas G. Welch

DOUGLAS G. WELCH, Jr.
Supervisor, Water
Conservation

Enclosure

ARNOLD
(11)

KNELL'S COMMENTS FOR FILES 400.01

Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley

DRAFT FINAL REPORT December 1999

Grant Agreement No. B-80560

Khaled M. Bali
Farm Advisor, Irrigation/Water Management
University of California Cooperative Extension
UC Desert Research and Extension Center
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Richard L. Snyder
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Land, Air and Water Resources - Atmospheric Science
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COOPERATIVE EXTENSION
UNIVERSITY OF CALIFORNIA
IMPERIAL COUNTY

1050 E. HOLTON ROAD
HOLTVILLE, CA 92250-9615

TELEPHONE:
(760) 352-9474

FAX NUMBER:
(760) 352-0846

December 31, 1999

Dr. Baryohay Davidoff
Mr. Wayne Verrill
Office of Water Conservation
California Department of Water Resources
1020 Ninth Street, 3rd Floor
Sacramento, CA 95814
Tel: 916-327-1828
Fax: 916-327-1815

Re: Draft final report, Contract No. B-80560: Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley Project

Attached please find our draft final report for the above project. Please review the attached report and send your comments to us by February 29, 2000. Thank you for your time and attention.

Sincerely,

Khaled Bali

Khaled M. Bali
Farm Advisor
Irrigation/Water Management.

Enc.

C: Steve Jones, USBR
Steve Kenell, IID
Rick Snyder, UCD
Mark Grismer, UCD
Ian Tod, UCD
Juan Guerrero, UCCE
Refugio Gonzalez, UCCE

Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley

DRAFT FINAL REPORT December 1999

Grant Agreement No. B-80560

Khaled M. Bali
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DRAFT FOR DISCUSSION ONLY

Data presented in this report are preliminary *and not for publication* until authorized by the investigators – December 1999

Table of Contents

Executive Summary:

Colorado River water is the lifeblood of the Imperial Valley as it is the only source of irrigation and drinking water in the Valley. As much as 2.8-3.0 million acre-feet (MAF) out of an recently agreed upon allotment of 3.1 MAF of Colorado River water are used every year to irrigate more than 500,000 acres of land in the Imperial Valley. Surface and subsurface drainage water from irrigated fields enter the Salton Sea, the drainage sink for the Imperial and Coachella Valleys since its formation in 1905. The Sea continues to exist because of agriculture drainage water from these Valleys as well as agricultural drainage and untreated and partially treated sewage from the Mexicali Valley. Because of drainage and its impact on the Sea, several water quality issues exist in the Imperial Valley in which water conservation plays a role.

Not true inaccurate representation of quantity

not a new method / not used @ site

This report describes the development of a new method to minimize or eliminate surface runoff (tailwater) from irrigated forage crops grown on heavy clay soils of the Imperial Valley. It also presents the best management practices (BMP's) to achieve the above objective and describes the demonstration project that was conducted at the University of California Desert Research & Extension Center (UCDREC) between 1995 and 1999 to evaluate the effectiveness of this new method.

An alluvial, moderately saline (EC⁻ 6-8 dS/m in the rootzone) clay soil at UCDREC, Holtville, CA, was cultivated and sudangrass was planted in April 1996, April 1997, and April 1998 (Field No. 1). Alfalfa was planted in November 1995 (Field No. 2) followed by a corn planting on the same ground in February 1999. A total of 15 acres were used in this project. The area was divided into 2 fields each containing separate plantings of alfalfa (followed by corn) and sudangrass. Each field contained 4 borders; each border was 65 ft wide and approximately 1250 ft long. Thirty-two sampling locations were established in each field to determine soil moisture, water table elevation and quality, and soil salinity at different depths. Moisture contents at all sampling locations were measured using a neutron probe. Soil moisture measurements were made prior to irrigation and 2 or 3 days after irrigation. Alfalfa and sudangrass hay yields were determined for every cutting.

Significant amount of runoff water was saved as a result of the implementation of this method. Overall only 2% of the applied water became runoff resulting in a significant increase in water application efficiency. Additional water savings were obtained by reducing the frequency of water application from two to one irrigation per alfalfa cutting cycle. The effect of reduced surface runoff irrigations on alfalfa yield was only minimal (less than 2% reduction). Sudangrass yield was not affected by the surface runoff reduction treatment and resulted in similar water savings. Alfalfa and sudangrass hay quality was not affected by the implementation of the runoff reduction method. We obtained average applied water use efficiencies (AWUE's) of 1.77 tons of sudangrass per ac-ft/ac and 1.76 dry tons of alfalfa per ac-ft/ac. The corresponding WUE (includes AW, rain and WT contributions to ET of the crop) figures for sudangrass and alfalfa were 1.75 and 1.54, respectively. This alfalfa AWUE value (i.e. 1.76) compared more favorably with the CA and AZ statewide (1998) average AWUE's of 1.80 and 1.49 dry tons of alfalfa per ac-ft/ac, respectively, as compared to the Imperial Valley (1996-1998) average AWUE of 1.17 tons of alfalfa per ac-ft/ac.

We found that shutting off the applied water at when the surface wetting front reached approximately 70-75% of the field's length resulted in sufficient water coverage to irrigate the entire border while reducing runoff to only 1-6% of the applied water. For the first irrigation, a cutoff distance of approximately 80-85% of the field's length is recommended and adequate to ensure that enough water reaches the lower end of the field. The method of Grismer and Tod (1994) may be used to estimate the volume of cracks and cutoff distance or time in heavy soils for all irrigations after the first irrigation in the growing season.

this is not significant?

why?

Water table contribution (WTC) to alfalfa crop evapotranspiration was only significant during the first year of the study. Water table contribution accounted for approximately 18% of alfalfa crop water use during the first year of the study and only 11% during the entire alfalfa growing period (Nov. 95 through Aug. 98). The average alfalfa crop coefficient for the entire alfalfa growing period was approximately 0.84. After three years, the average crop coefficient for sudangrass during the entire growing seasons was approximately 0.81.

An increase in soil salinity of the alfalfa field was observed as a result of the upward movement of water from the saline water table. However, soil salinity levels after leaching and planting a salt sensitive crop (sweet corn) were at or below salinity levels at the beginning of the experiment. Soil salinity in the sudangrass field did not increase as a result of the implementation of the runoff reduction method.

Additional work is needed to verify the applicability of this method to commercial fields and under conditions where irrigation water deliveries are set for either 12 or 24-hour orders as is common in the Imperial Valley.

Should clarify more the fact that a reservoir was used which allowed a level of flexibility not available to ~~commercial~~ commercial growers of alfalfa or sudan.

Preface

The purpose of the Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley Project was to improve irrigation efficiency by reducing surface runoff, utilizing the shallow saline watertable, and determination of crop coefficients for the two common field crops (alfalfa and sudangrass) to increase utilization of CIMIS reference evapotranspiration data for irrigation scheduling in the Valley. The main activity of the project was field trials undertaken to develop and demonstrate a new method of predicting irrigation cutoff time to reduce or eliminate surface runoff.

The report is laid out in two sections. In Section I, the Best Management Practices (BMP) for Irrigation Management and Surface Runoff Reduction from Heavy Clay Soils are presented. The BMP are based on the findings of the field trials. In Section II, the field trials are described in detail and the results are presented and analyzed.

DRAFT FOR DISCUSSION ONLY

Data presented in this report are preliminary *and not for publication* until authorized by the investigators – December 1999

SECTION I

Best Management Practices for Irrigation Management and Surface Runoff Reduction in Heavy Clay Soils

By

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Agricultural Drainage Reduction Program, Office of Water Conservation.
Contract No. B-80560

1.1 Introduction:

range?

Colorado River water is the only source of irrigation and drinking water in the Imperial Valley. Approximately 17% of the irrigation water delivered in the Imperial Valley later re-appears as tailwater. Efficient irrigation practices are needed to minimize surface runoff and to reduce the amount of chemicals translocated downstream in runoff water. The Salton Sea water surface elevation has recently reached the highest level on record since 1920. Surface runoff and subsurface drainage water from agricultural lands in Imperial Valley contribute to this increase in Salton Sea elevation. Currently, the salinity of the Sea is over 47,000 ppm, approximately 30% greater than the salinity of the Pacific Ocean.

Issues related to salinity, irrigation management, and water quality are also addressed in this report. The focus of this report is on field crops, specifically alfalfa and sudangrass. In 1998, field crops accounted for almost 80% of the nearly 500,000 acres of irrigated land in the Imperial Valley while heavy clay soils represents more than 60% of the irrigated land. Alfalfa and sudangrass water use account for more than 50% of the total crop water use in the Valley.

This publication summarizes the results of work conducted by the authors at the University of California Desert Research and Extension Center (UCDREC) to develop and demonstrate a simple field procedure to determine the irrigation cutoff time in cracking clay soil so that runoff losses are minimized. This research and demonstration project was conducted at UCDREC to verify the effectiveness of this method and its possible impact on alfalfa and sudangrass production in the Imperial Valley. The Center clay soils are typical of a major portion of the Imperial Valley.

Not true! Even NRCS says this is not true.

1.2 Objective

The objective of this Handbook is to introduce a simple and a practical method to reduce or eliminate surface runoff from irrigation of heavy clay soils. Such soils represent more than 60% of the nearly 500,000 acres of irrigated land in the Imperial Valley, CA. Approximately 17% of the irrigation water is lost to surface runoff due to the limited infiltration in clay soils. Water penetration is usually limited to free water flow into and through cracks. Grismer and Tod (1994) developed and tested a field procedure to estimate irrigation cut-off time for cracking clay soils using a volume balance method that is applied here.

1.3 Irrigation Cutoff-time method:

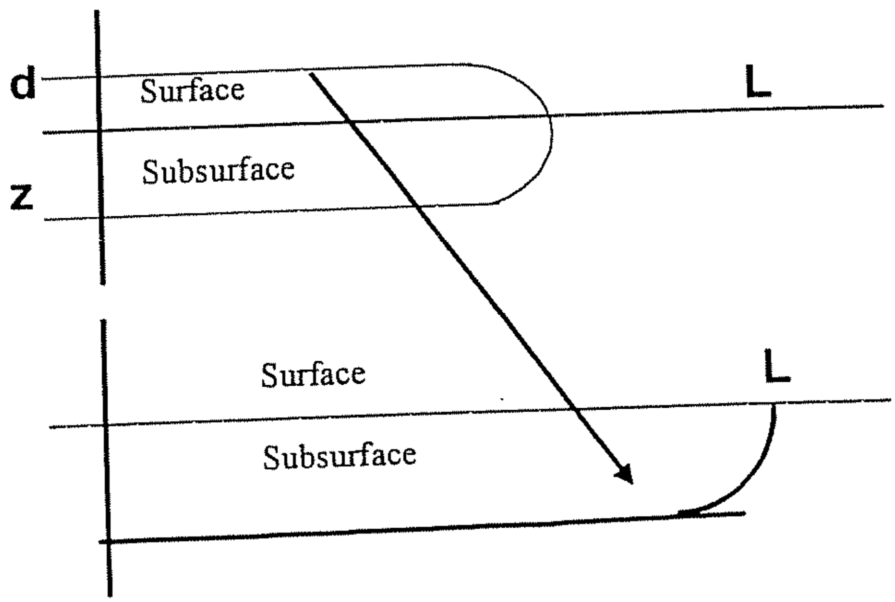
Irrigation scheduling can be based on a relatively simple technique that predicts the cut-off time necessary to minimize runoff and to improve water use efficiency. While the method is applicable for all soils it works best with heavy clay soils. The method is a combination of a volume balance model and a two-point measurement method. When applying the method to clay soils, the main objective is to irrigate using sufficient water to fill soil cracks with little or no runoff. The cut-off time or cut-off distance can be calculated for a given border check layout knowing that the total volume of water applied equals that volume stored on the surface plus that below (subsurface storage).

During an irrigation event, the volume of applied water can be estimated from onflow rate and time since irrigation began. The surface storage is the product of the average depth of water and the area covered by water. Similarly, the volume of the subsurface storage is essentially the volume of soil cracks. The method of Grismer and Tod (1994) can be used to estimate the volume of the cracks and then estimate the amount of water needed to irrigate the field with little or no runoff. Figure 1 schematically illustrates this concept as applicable to border-irrigated heavy clay soils. Variations of this method could be used on other soil types and/or furrow-irrigated fields.

The following parameters are needed to use the cut-off time method to determine the irrigation onflow time necessary to minimize or eliminate runoff:

1- Border width and length (feet).
2- Average onflow rate (cfs).
3- Advance rate (ft/min) <u>or</u> one or two points of water advance (ft) with time along the border.

Fig. 1.



We have developed simple graphs and charts that can be used by irrigators to estimate irrigation cut-off time or cut-off distance and the average depth of application. We have also developed an Excel spreadsheet and a stand-alone computer program for farm managers and irrigation personnel who are interested in irrigation evaluation or to customize graphs or charts for particular fields. These additional tools are not designed for or needed by irrigators to use this method in the field. Tables 1-7 can be used to estimate the necessary cut-off times or cut-off distances to eliminate or reduce surface runoff in heavy clay soils. While these tables are designed for borders having ¼-mile runs (approximately 1200-1300 ft runs), they can be adapted for use on ½-mile runs by simply doubling the irrigation time. Onflow rates typically range from 2-3 cfs per 65 ft wide borders at the UCDREC that served as the basis of the Tables and Charts.

1250×1250'

Typical water orders for a 40-acre field (36-38 acres of net irrigated area) in the Imperial Valley range from 7-10 cfs (approximately 14-20 ac-ft) such that 2- 4 borders can be irrigated at a time depending on border width. Most fields in the Imperial Valley are on slopes ranging between 0.1 - 0.2% (approximately 1-2 ft drop per 1000 ft of run). The following examples illustrate the use of the Tables and Charts to determine the irrigation cut-off time or cut-off distance necessary to eliminate surface runoff.

1.4 Determination of cutoff-distance:

Based on our experience in heavy clay soils in the Imperial Valley, the cutoff distance for most ¼-mile run borders is between 850 and 1050 ft for wide range of flow rates and field conditions. The cut-off distance can be estimated from simple measurements. The irrigator needs three stakes, watch and a tape measure. The following example illustrates this concept:

For ¼-mile run,

1- Place one stake at 300 ft from the water inlet
2- Place the second stake at 400 ft from the inlet
3- Place the third one at 1000 ft from the inlet
4- Determine the time it takes for the water to advance from the 1st stake to the second one
5- Use Table 2 to estimate the cut-off distance
6- The third stake could be use as a guide to turn the water off as the water approaches the estimated distance

Assumption list needed before this
- Assuming steady flow condit

Example 1:

Given a field that has 65 ft x 1200 ft borders, determine the cut-off distance when irrigating in sets of 4 borders and with a water order of approximately 9 cfs (approximately 18 ac-ft in 24 hr period).

- Average flow rate per border = 9 cfs/4 = 2.25 cfs/border
- Determine the time it takes for the water to advance from 1st stake to the 2nd one. For

1200' × 1200' field
1200'/65' ≅ 18 or 19 borders
18/4 or 19/4 = odd # of sets. Need either 16 or 20 borders for this to work.

this example, 26 minutes were required for the surface water to advance between the first and second stake

- Use Table 1 (for an onflow rate of 2.2 cfs) to find the cut-off distance. In this example, we look under the advance time of 26 minutes. The corresponding cut-distance is approximately 970 ft down the border.

1.5 Determination of cut-off time:

Example 2:

Given a field that has 65 ft x 1200 ft borders, determine the cut-off time when irrigating in sets of 4 borders and with a water order of approximately 9 cfs (approximately 18 ac-ft in 24 hr period).

- Average flow rate per border = 9 cfs/4 = 2.25 cfs/border
- Measure the advance rate; that is, the time it takes for the water to advance some distance between 100 and 500 ft along the border. For this example, 40 minutes were required for the surface advance to reach 150 ft from the turnout.
- Compute the advance rate. In this example, 150 ft/40 minutes = 3.75 ft/min.

Use Table 3 (for an onflow rate of 2.2 cfs) to find the cut-off time. In this example, we look under the advance rate column for a value close to 3.75; choosing 3.8, the corresponding cut-off time is approximately 255 minutes or when the water reaches approximately ~~970~~ ft down the border. The average depth of application is also given at approximately 5.2 inches.

2.0 100% smd
1.5
1.0
.5
5.0

This is A heavy Application for clay Soil

Example 3:

In the same manner, Fig. 3 can be used to estimate the irrigation cut-off time and average depth of application. Use the information from Example 1 (onflow rate of 2.25 cfs and advance rate of 3.75 ft/min) to estimate the irrigation cut-off time and average depth of application.

- Using Figure 3, draw a vertical line at an advance rate of approximately 3.75 and read the cut-off time that crosses the irrigation cut-off time curve; that is, approximately 260 minutes. Similarly, Figure 3 shows a corresponding average depth of application of approximately 5.25 inches.

1.6 Determination of cutoff time or distance from pre-determined soil moisture depletion

If you know that the average depth of application (or average soil moisture depletion is 5.2 inches) before the irrigation event, you can determine the irrigation cut-off time and distance from Figures 8-13.

Example 4:

Again using the field information from Example 1, determine the cut-off time and distance for a soil moisture depletion level of 5.2 inches.

> -Using Figure 9, draw a vertical line at a soil moisture depletion level of 5.2 inches and read the cut-off distance that crosses the irrigation cut-off time curve; that is, the irrigation cut-off time is approximately 255 minutes and the irrigation cut-off distance is approximately 975 ft.

Please note that the information in Tables 1-7 and Figures 2-13 are for borders that are 65 ft wide and 1200 ft long and for a slope of 0.1%.

An Excel spreadsheet can be used to generate tables and figures for various combinations of flow rates, slopes, and border-check dimensions of interest.

Example 5:

Use the information in Example 1 to determine the cut-off time, cut-off distance and average depth of application using the Excel spreadsheet.

- Border width 65 ft, border length 1200 ft, average flow rate 2.25 cfs per border, it took 40 minutes for the water to advance 150 ft.
- Enter the above information into the spreadsheet
- Cutoff time = 260 minutes
- Cutoff distance = 976ft
- Average depth infiltrated = 5.40 inches

1.7 Additional information

For additional information or for customized tables or figures for your field, please feel free to use the enclosed spreadsheet, or contact us at 760-352-9474 or via e-mail at kmbali@ucdavis.edu.

Overview
~~System~~ represents an assumption of absolutes.
Methodology
- Absolute soil uniformity
- Absolute consistent infiltration
- Uniform sand throughout field
-

Table 1. Irrigation Cut-off distance for border-irrigated alfalfa field
(Border width 65 ft, border length 1200 ft, slope 0.1%)

Time (min)/100 ft of advance	Estimated cut-off distance (ft) ****************** Flow rate (cfs)*****************				
	2.0	**2.2**	**2.4**	**2.6**	**2.8**
16				845	855
18	850	865	875	885	895
20	890	890	910	920	925
22	915	925	935	945	950
24	940	950	955	965	970
26	960	970	975	985	990
28	975	985	990	100	1005
30	990	1000	1005	1010	
32	1000	1010	1020		
34	1015	1020			
36	1025	1030			

Table 2. Irrigation Cutoff time for border-irrigated alfalfa field
(Flow rate 2.0 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.0	337	1010	6.23
3.2	312	1000	5.77
3.4	290	985	5.36
3.6	271	975	5.00
3.8	253	960	4.67
4.0	237	950	4.38
4.2	223	935	4.12
4.4	210	925	3.88
4.6	198	910	3.66
4.8	187	900	3.46
5.0	177	885	3.27
5.2	168	875	3.10

Table 3. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 2.2 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.2	315	1005	6.39
3.4	293	995	5.94
3.6	273	985	5.54
3.8	255	970	5.19
4.0	240	960	4.87
4.2	225	945	4.58
4.4	212	935	4.31
4.6	200	920	4.07
4.8	190	910	3.85
5.0	180	900	3.65
5.2	170	885	3.46
5.4	162	875	3.29

Table 4. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 2.4 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.4	295	1000	6.53
3.6	275	990	6.09
3.8	257	980	5.70
4.0	242	965	5.35
4.2	227	955	5.04
4.4	214	945	4.75
4.6	203	930	4.49
4.8	192	920	4.25
5.0	182	910	4.03
5.2	172	895	3.82
5.4	164	885	3.63
5.6	156	875	3.46

Table 5. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 2.6 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.4	296	1010	7.12
3.6	277	995	6.64
3.8	259	985	6.22
4.0	244	975	5.84
4.2	229	965	5.50
4.4	216	950	5.19
4.6	204	940	4.91
4.8	194	930	4.64
5.0	184	920	4.40
5.2	174	905	4.18
5.4	166	895	3.98
5.6	158	884	3.79

Table 6. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 2.8 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
3.8	261	990	6.75
4.0	245	980	6.34
4.2	231	970	5.97
4.4	218	960	5.63
4.6	206	950	5.33
4.8	195	940	5.04
5.0	185	925	4.79
5.2	176	915	4.55
5.4	167	905	4.33
5.6	159	890	4.12
5.8	152	880	3.93
6.0	145	870	3.75

Table 7. Irrigation Cutoff time for border-irrigated alfalfa field.
(Flow rate 3.0 cfs, border width 65 ft, border length 1200 ft, slope 0.1%)

Advance rate (ft/min)	Estimated Cut-off time (min)	Estimated Cut-off distance (ft)	Estimated Infiltrated depth (in)
4.0	247	985	6.83
4.2	232	975	6.44
4.4	219	965	6.08
4.6	208	955	5.75
4.8	197	945	5.45
5.0	187	935	5.17
5.2	177	925	4.91
5.4	169	910	4.68
5.6	161	900	4.46
5.8	154	890	4.25
6.0	147	880	4.06
6.2	140	870	3.88

Figure 2. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.0 cfs

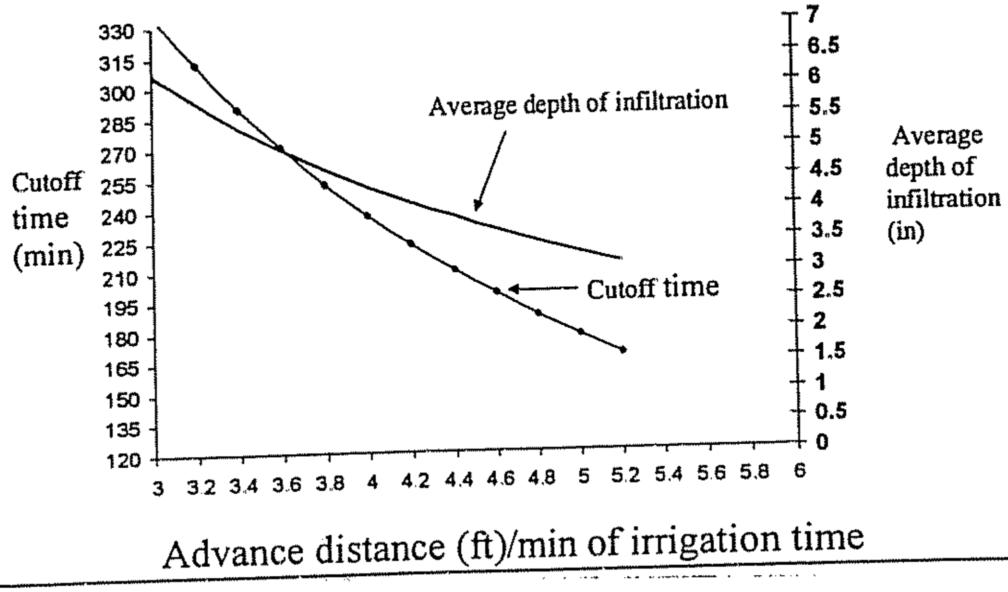


Figure 3. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.2 cfs

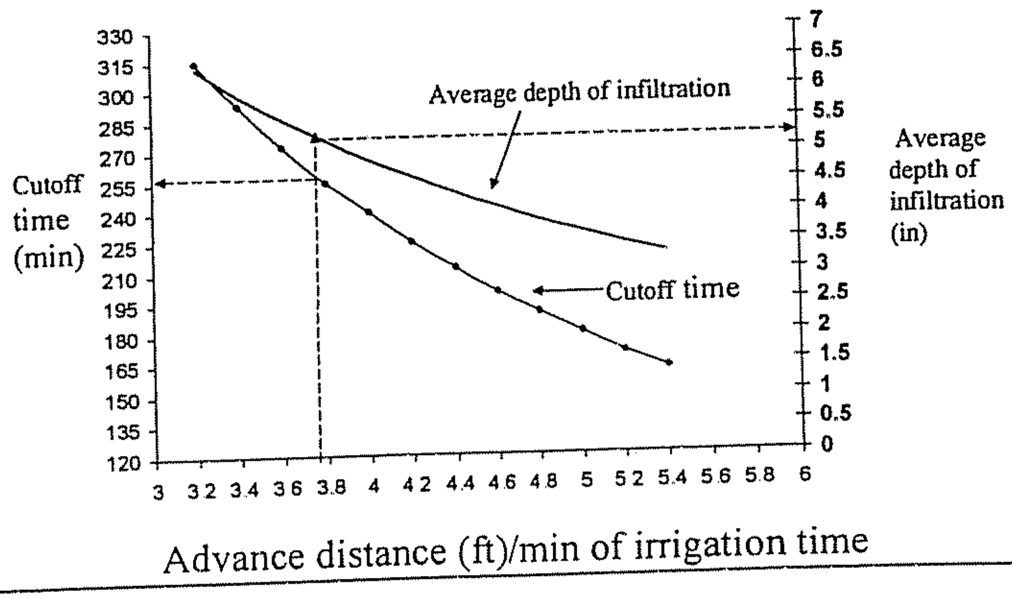
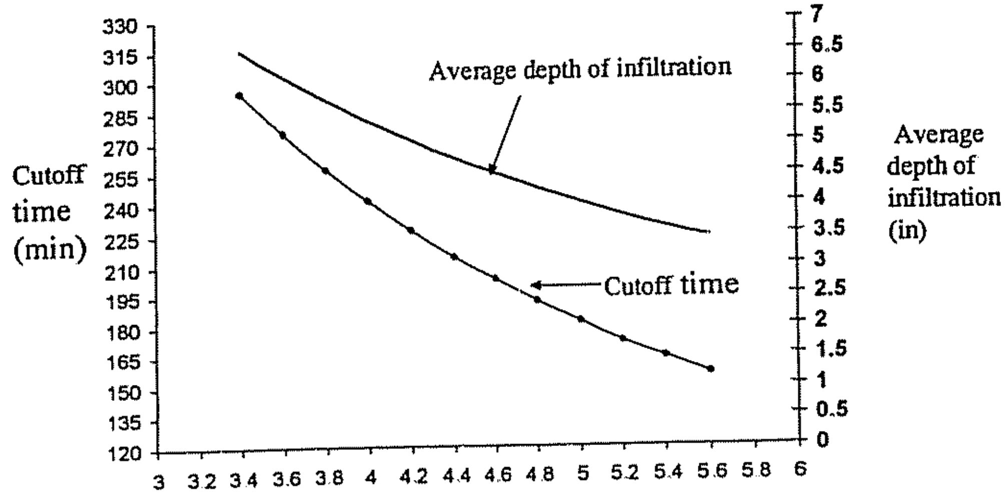
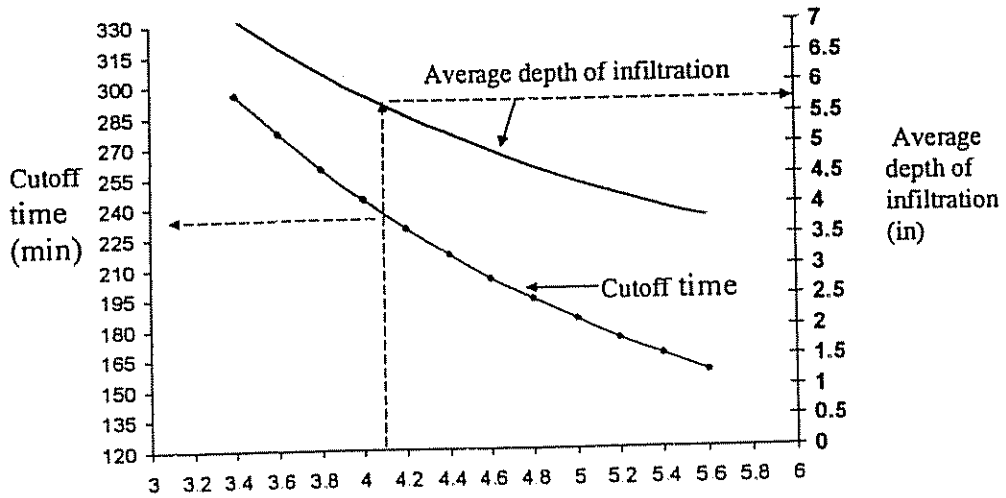


Figure 4. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.4 cfs



Advance distance (ft)/min of irrigation time

Figure 5. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.6 cfs



Advance distance (ft)/min of irrigation time

Figure 6. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.8 cfs

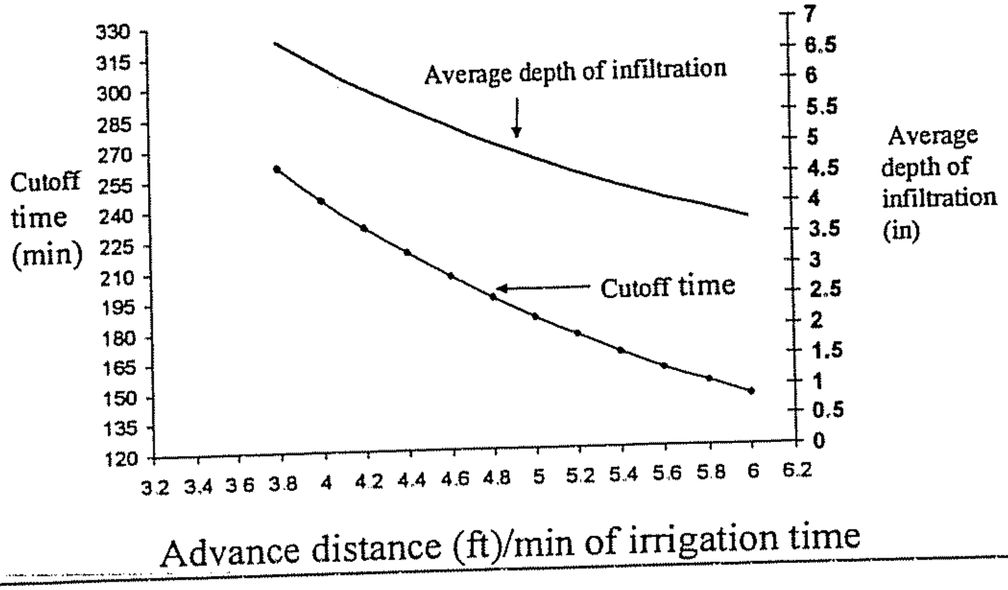


Figure 7. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=3.0 cfs

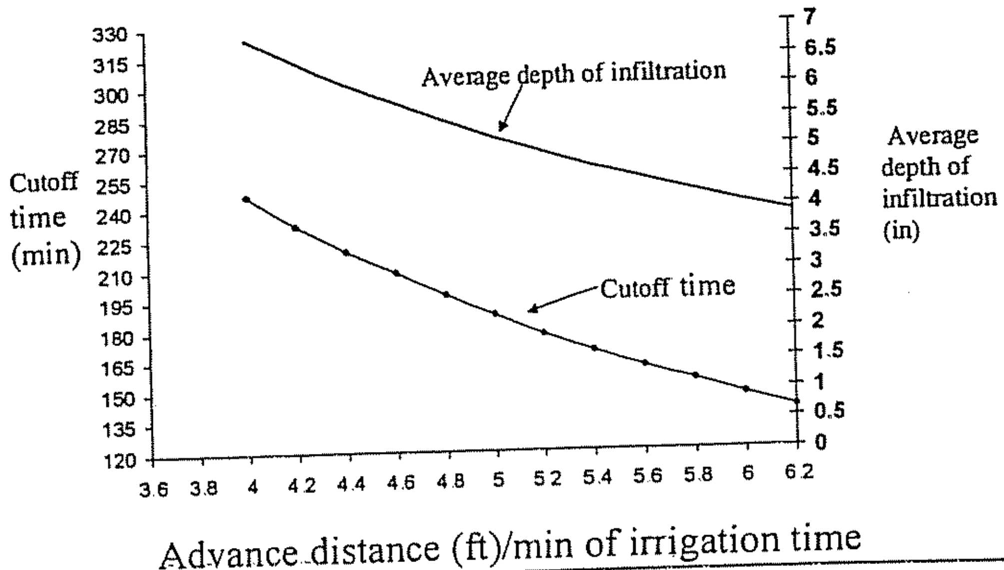


Figure 8. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.0 cfs

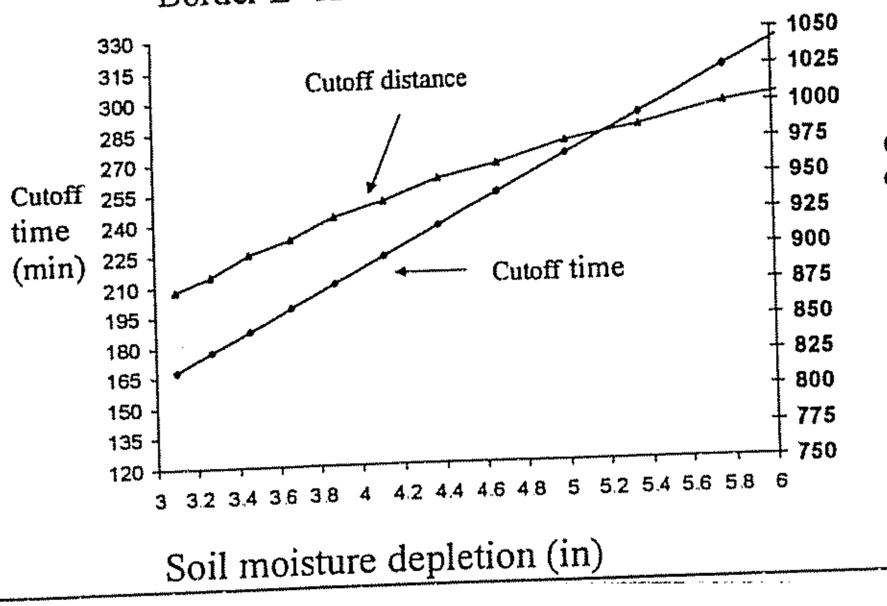
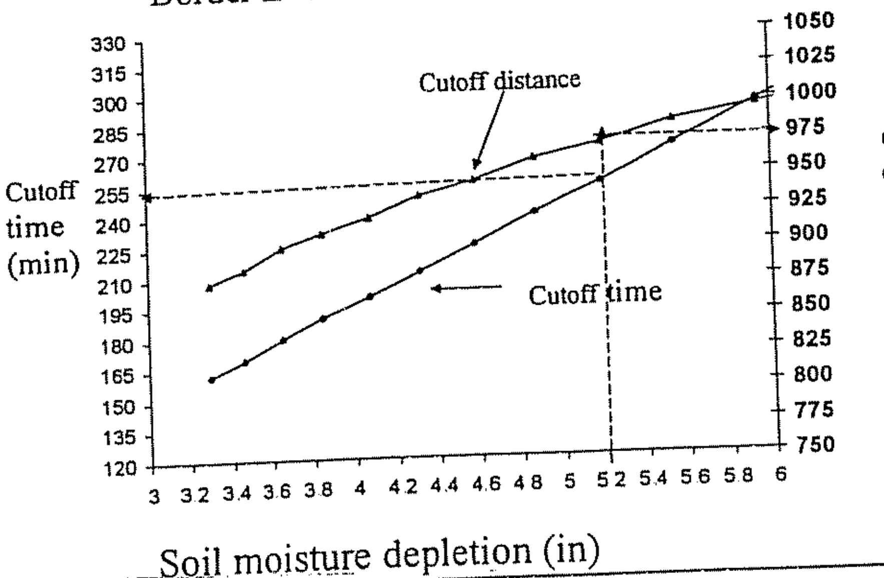


Figure 9. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.2 cfs



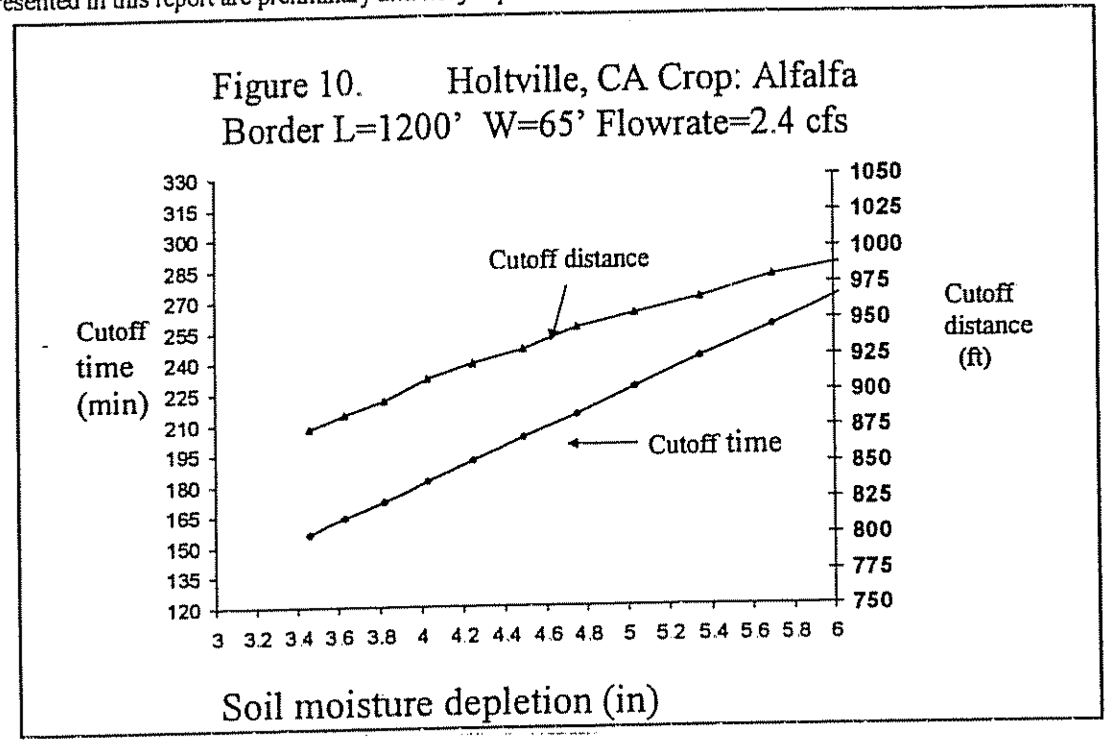


Figure 10. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.4 cfs
Cutoff distance
Cutoff time
Cutoff time (min)
Cutoff distance (ft)
Soil moisture depletion (in)

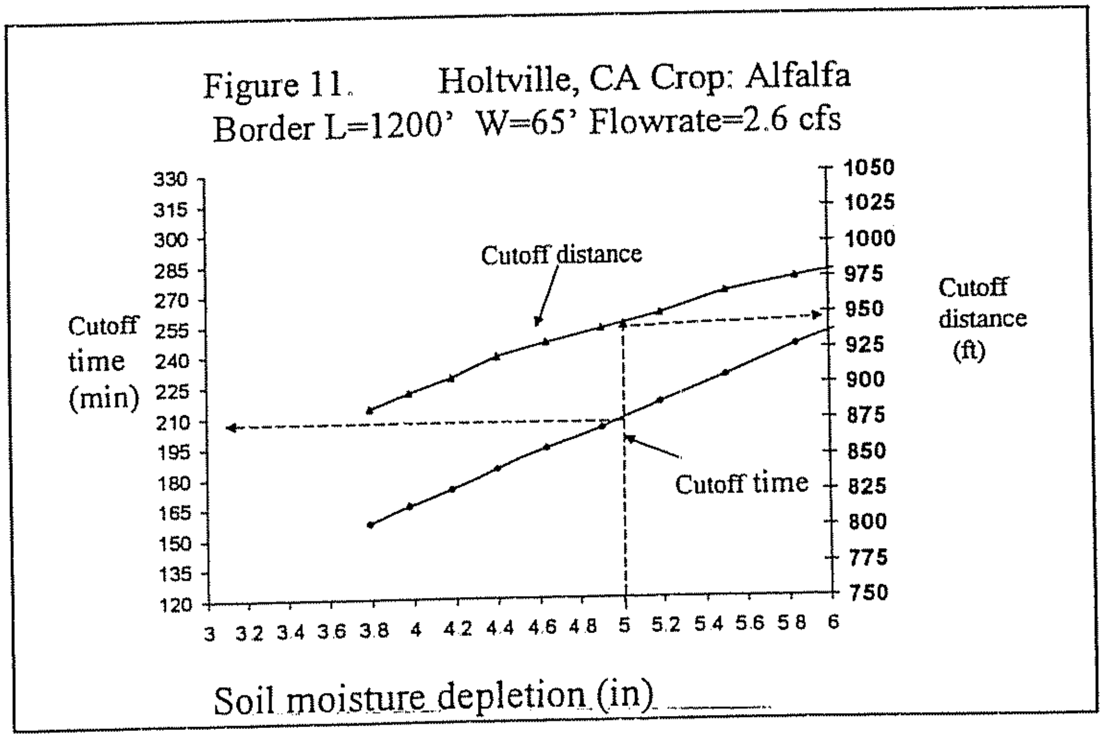


Figure 11. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.6 cfs
Cutoff distance
Cutoff time
Cutoff time (min)
Cutoff distance (ft)
Soil moisture depletion (in)

Figure 12. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=2.8 cfs

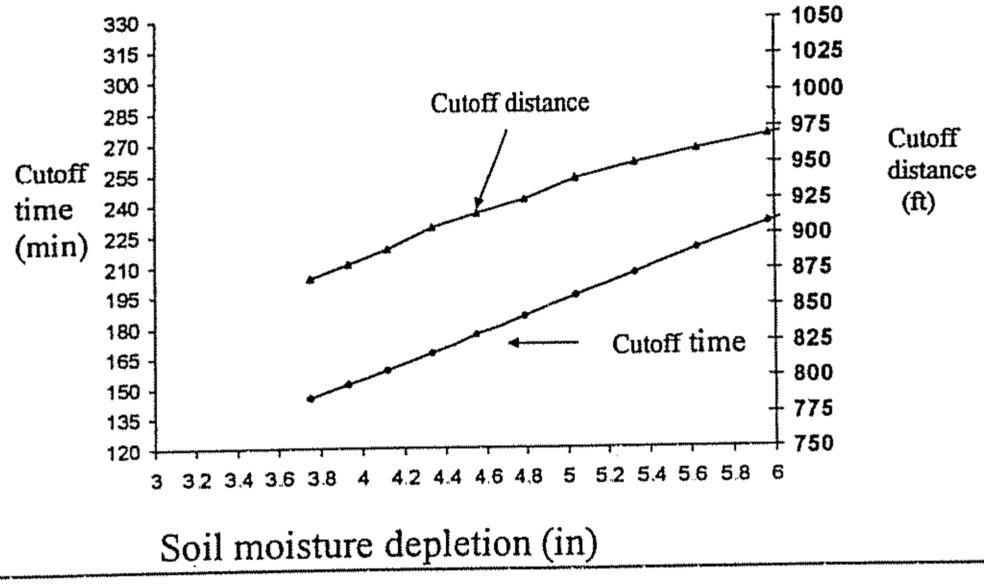
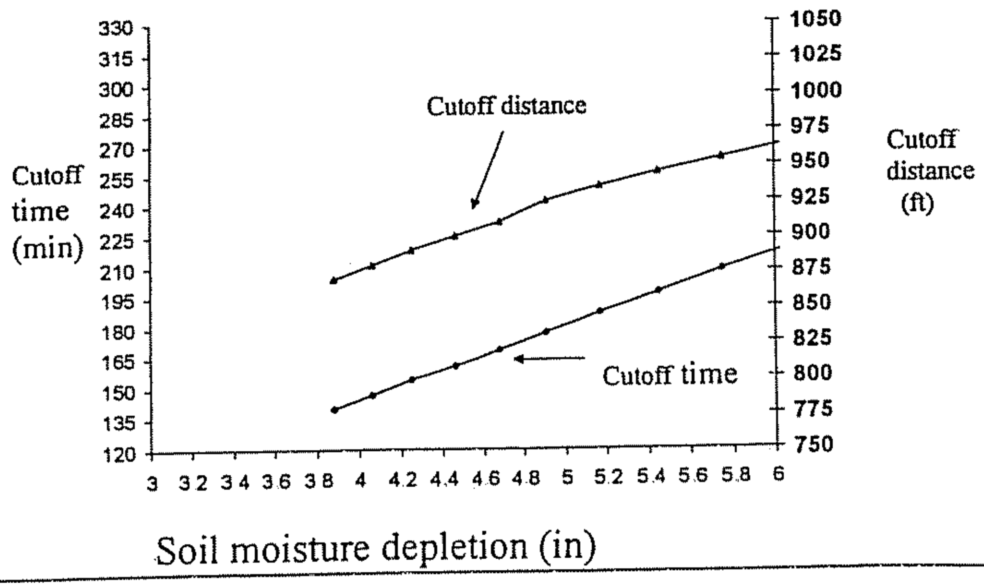


Figure 13. Holtville, CA Crop: Alfalfa
Border L=1200' W=65' Flowrate=3.0 cfs



1.8 Determination of heavy clay soil water-holding characteristics.

Soil-water holding characteristics can best be determined from soil cores taken from the field, but useful estimates can often be made from data available in soil survey reports. Estimated field capacity and available water capacity reported here are based on data from USDA Soil Conservation Service (NRCS) soil survey reports.

Table 8. Soil water-holding characteristics of Imperial County heavy clay soils.

			Available Water (in/in) *Depth (inches)*			Field Capacity (in/in) *Depth (inches)*		
Series	Symbols	Maximum Depth (in)	0-24	24-48	48+	0-24	24-48	48+
Glenbar	105, 106, 115, 116	60	0.20	0.20	0.20	0.39	0.39	0.39
Imperial	111, 112, 114	60	0.21	0.21	0.21	0.42	0.42	0.42

* Water-holding Characteristics of California Soils- University of California-DANR Leaflet 21463

How do the soils of the trial site compare to these values?

1.9 Computer program

The attached IBM formatted diskette contains a user-friendly computer program that considers practical applications of the runoff reduction method described above. The program includes educational elements about water quality and soil salinity as well as practical applications of surface runoff reduction method. To run the program:

- Windows 95/98, just double click on the SRRP2.EXE file and then follow instructions on the screen
- DOS: at the DOS command, just type **SRRP2.EXE** and then follow instructions on the screen

The computer program is a stand-alone application and does not require any other application/software. The disk also contains sample output files.

References:

Grismer, M. E. And I. C. Tod. 1994. Field evaluation helps calculate irrigation time for cracking clay soils. Cal. A. 48(4):33-36.

Water-holding Characteristics of California Soils- University of California-DANR Leaflet 21463.

Appendix 1: Excel Spreadsheet

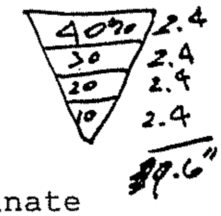
```
File: Coftime3
Irrigation Date:
Field ID:
Border or set No:
Field
Characteristics:
      Border length (ft)   L=      1200
      Border width (ft)    W=        65
      Field slope          S=     0.001
      (ft/ft)
      Surface roughness
        & crop maturity    n=     0.031
      (n=.014-.017 for newly planted
      crop)
      (n=0.017-.031 for mature
      crop)
Measurements                                     Advance ratio
:
      Flowrate             Q=      2.25             (ft/min)
      (cfs):
      Advance time (min)   t=        40                3.8
      Advance distance     Lx=      150
      (ft)
************************************************************
********
**    Estimated average depth of           5.40  inches   **
      infiltration:
**                                                        **
**    Estimated cutoff                      260  minutes  **
      time:
**    Estimated cutoff distance:            976  ft       **
************************************************************
********
```

APPENDIX 2

Sample output of SRRP2.

```
File Name: output
 Crop: Alfalfa
 Irrigation Management & Surface Runoff Reduction Program
 SRRP ver. 1.0  APR. 1997  K. M. Bali, UCCE
 Copyright (c) 1997, Version 1.00  DRAFT

 ----------------------------------------
 Border length (ft):    1200
 Border width (ft):       65
 Field slope (ft/ft):    .0010
 Crop maturity factor:    .0310
 Flow rate per border in cfs:  2.250
 Advance distance in ft:    150
 Advance time in minutes:    40.
 Desired application depth (in):   5.00
 -----------------------------
 Infiltrated water depth:   5.40 inches
 Estimated cutoff time to reduce or eliminate
 surface runoff:    260. minutes
```



5/96 = 50% depletion

Irrigating time (minutes)	App. Eff. (%)	Deep Perc. (%)	Runoff (%)
260.	92.5	7.5	.0
270.	89.1	7.2	3.7
280.	85.9	6.9	7.1
290.	83.0	6.7	10.3
300.	80.2	6.5	13.3
310.	77.6	6.3	16.1
320.	75.2	6.1	18.7
330.	72.9	5.9	21.2

Appendix 3:

Surface Irrigation Cutoff Time Calculations

Field Identification:__________________ Date:__________________________

Border Number: __________________

Surface Roughness (n)

newly planted	$0.014 \le n \le 0.017$
crop near maturity	$0.023 \le n \le 0.031$

Field Characteristics:

Border length (ft) L = __________
Border width (ft) w =__________
Field slope (%) s =__________
Crop & maturity n =__________

Measurements:

Onflow rate (cfs) Q =__________
Advance time (min) t =__________
Advance dist. (ft) Lx=__________

{These measurements are taken when the surface wetting front has advanced 1/4 to 1/3 of the border length down the field.}

Flow depth (ft) d $=[Q*n/(1.486*w*\sqrt{s})]^{0.6}$ = ____________

Total volume applied (ft3) TAW = Q*t*60 = ____________
Surface water volume (ft3) SW = Lx*w*d = ____________
Infiltrated (crack) water volume (ft3) IW =TAW-SW = ____________

Infiltrated water depth (ft) z = IW/(Lx*W)= ____________

Cutoff time (min) L*W*Z/(Q*60) = ____________

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Summary of Field Trials

1.1 Executive summary

Colorado River water is the lifeblood of the Imperial Valley as it is the only source of irrigation and drinking water in the Valley. As much as 2.8-3.0 million acre-feet (MAF) out of a ~~a recently agreed upon allotment of~~ 3.1 MAF of Colorado River water are used every year to irrigate more than 500,000 acres of land in the Imperial Valley. Surface and subsurface drainage water from irrigated fields enter the Salton Sea, the drainage sink for the Imperial and Coachella Valleys since its formation in 1905. The Sea continues to exist because of agriculture drainage water from these Valleys as well as agricultural drainage and untreated and partially treated sewage from the Mexicali Valley. Because of drainage and its impact on the Sea, several water quality issues exist in the Imperial Valley in which water conservation plays a role.

This report describes the development of a ~~new~~ method to minimize or eliminate surface runoff (tailwater) from irrigated forage crops grown on heavy clay soils of the Imperial Valley. It also presents the best management practices (BMP's) to achieve the above objective and describes the demonstration project that was conducted at the University of California Desert Research & Extension Center (UCDREC) between 1995 and 1999 to evaluate the effectiveness of this new method.

An alluvial, moderately saline (EC~ 6-8 dS/m in the rootzone) clay soil at UCDREC, Holtville, CA, was cultivated and sudangrass was planted in April 1996, April 1997, and April 1998 (Field No. 1). Alfalfa was planted in November 1995 (Field No. 2) followed by a corn planting on the same ground in February 1999. A total of 15 acres were used in this project. The area was divided into 2 fields each containing separate plantings of alfalfa (followed by corn) and sudangrass. Each field contained 4 borders; each border was 65 ft wide and approximately 1250 ft long. Thirty-two sampling locations were established in each field to determine soil moisture, water table elevation and quality, and soil salinity at different depths. Moisture contents at all sampling locations were measured using a neutron probe. Soil moisture measurements were made prior to irrigation and 2 or 3 days after irrigation. Alfalfa and sudangrass hay yields were determined for every cutting.

Significant amount of runoff water was saved as a result of the implementation of this method. Overall only 2% of the applied water became runoff resulting in a significant increase in water application efficiency. Additional water savings were obtained by reducing the frequency of water application from two to one irrigation per alfalfa cutting cycle. The effect of reduced surface runoff irrigations on alfalfa yield was only minimal (less than 2% reduction). Sudangrass yield

% value missing

was not affected by the surface runoff reduction treatment and resulted in similar water savings. Alfalfa and sudangrass hay quality was not affected by the implementation of the runoff reduction method. We obtained average applied water use efficiencies (AWUE's) of 1.77 tons of sudangrass per ac-ft/ac and 1.76 dry tons of alfalfa per ac-ft/ac. The corresponding WUE (includes AW, rain and WT contributions to ET of the crop) figures for sudangrass and alfalfa were 1.75 and 1.54, respectively. This alfalfa AWUE value (i.e. 1.76) compared more favorably with the CA and AZ statewide (1998) average AWUE's of 1.80 and 1.49 dry tons of alfalfa per ac-ft/ac, respectively, as compared to the Imperial Valley (1996-1998) average AWUE of 1.17 tons of alfalfa ~~per~~ ac-ft/ac.

Is this a new representation of water use eff.?

We found that shutting off the applied water at when the surface wetting front reached approximately 70-75% of the field's length resulted in sufficient water coverage to irrigate the entire border while reducing runoff to only 1-6% of the applied water. For the first irrigation, a cutoff distance of approximately 80-85% of the field's length is recommended and adequate to ensure that enough water reaches the lower end of the field. The method of Grismer and Tod (1994) may be used to estimate the volume of cracks and cutoff distance or time in heavy soils for all irrigations after the first irrigation in the growing season.

Water table contribution (WTC) to alfalfa crop evapotranspiration was only significant during the first year of the study. Water table contribution accounted for approximately 18% of alfalfa crop water use during the first year of the study and only 11% during the entire alfalfa growing period (Nov. 95 through Aug. 98). The average alfalfa crop coefficient for the entire alfalfa growing period was approximately 0.84. After three years, the average crop coefficient for sudangrass during the entire growing seasons was approximately 0.81.

An increase in soil salinity of the alfalfa field was observed as a result of the upward movement of water from the saline water table. However, soil salinity levels after leaching and planting a salt sensitive crop (sweet corn) were at or below salinity levels at the beginning of the experiment. Soil salinity in the sudangrass field did not increase as a result of the implementation of the runoff reduction method.

what was this amount of water / was this figured

Additional work is needed to verify the applicability of this method to commercial fields and under conditions where irrigation water deliveries are set for either 12 or 24-hour orders as is common in the Imperial Valley.

1.2 Introduction

Colorado River water is the only source of irrigation and drinking water in the Imperial Valley. Approximately 17% of the irrigation water delivered in the Imperial Valley later re-appears as tailwater. Efficient irrigation practices are needed to minimize surface runoff and to reduce the amount of chemicals translocated downstream in runoff water. The Salton Sea water surface elevation has recently reached the highest level on record since 1920. Surface runoff and subsurface drainage water from agricultural lands in Imperial Valley contribute to this increase in Salton Sea elevation. Currently, the salinity of the Sea is over 47,000 ppm, approximately 30% greater than the salinity of the Pacific Ocean.

Issues related to salinity, irrigation management, and water quality are also addressed in this report. The focus of this report is on field crops, specifically alfalfa and sudangrass. In 1998, field crops accounted for almost 80% of the nearly 500,000 acres of irrigated land in the Imperial Valley while heavy clay soils represents more than 60% of the irrigated land. Alfalfa and sudangrass water use account for more than 50% of the total crop water use in the Valley.

This publication summarizes the results of work conducted by the authors at the University of California Desert Research and Extension Center (UCDREC) to develop and demonstrate a simple field procedure to determine the irrigation cutoff time in cracking clay soil so that runoff losses are minimized. This research and demonstration project was conducted at UCDREC to verify the effectiveness of this method and its possible impact on alfalfa and sudangrass production in the Imperial Valley. The Center clay soils are typical of a major portion of the Imperial Valley. "Not so. Sand at 4 ft is not "typical" of "heavy clay""

2. Objectives/additional objectives

The original objectives of the project were to:

2.1 Determine ~~the~~ a best management practice~~s~~ (BMP~~s~~) for surface runoff reduction in heavy clay soils of the Imperial Valley.

2.2 Determine the effect of water table control on irrigation management and consumptive use of water by alfalfa and sudangrass (including crop coefficients for alfalfa and sudangrass).

2.3 Determine the contribution of shallow saline water tables to crop evapotranspiration in heavy clay soils.

2.4 Develop a relatively simple approach to predict irrigation cutoff time from pre-determined soil moisture measurements.

2.5 Develop a user-friendly computer program and irrigation management spreadsheets for efficient irrigation management practices. These tools include: the use of CIMIS data for irrigation scheduling, prediction of crop water requirements for alfalfa and sudangrass, and prediction of seasonal changes in AE, DU, and surface runoff.

2.6 Conduct field days, demonstrations, seminars, and publish results in both popular and scientific media.

Additional objectives were added during the course of the experiment to address concerns/issues that were raised during the Project Advisory Committee (PAC) meetings. These included addressing the following concerns:

2.7 Assess the impact of runoff reduction on hay quality.
2.8 Assess the impact of runoff reduction on soil salinity.
2.9 Evaluate alfalfa root distribution.
2.10 Assess the impact of the runoff reduction method on subsequent crop production.
2.11 Assess the impact of two irrigation per cutting versus one irrigation per cutting on alfalfa yield in summer 1997.

3. Methodology

Alluvial clay soil of Areas 70 and 80 at the UCDREC, Holtville, CA, was cultivated. The 15-acre project area was divided into 2 fields each containing separate plantings of alfalfa and sudangrass. Alfalfa was planted in November 1995 (Field No. 2). Sudangrass was planted in April 1996, April 1997, and April 1998 (Field No. 1). Each field contained 4 borders where each border was 65 ft wide and approximately 1250 ft long. Thirty-two sampling locations were established in each field to evaluate soil moisture distribution and soil salinity at different depths (Figure 14). Moisture contents at all sampling locations were determined using a neutron probe as described by Grismer et al. (1995). Soil moisture measurements were made prior to and 2 or 3 days after irrigations. Colorado River water was applied to all fields. During the first year of the study, most irrigations began between 6-7 am and ended between 5-7 PM. ~~We used a~~ A reservoir was used at UCDREC, that was filled with water from an IID canal the previous day, to start the irrigations for approximately 2-3 hours until IID canal water became available at approximately 9 AM. At the end of each irrigation excess water ordered from the IID was stored in the reservoir to irrigate other crops at the Center (IID water orders were for either 12 or 24-hour runs). During the last year of the project and in response to issues raised by the PAC, we changed the timing of the irrigations such that we started the irrigation in either the afternoon (4-7PM) or at night (11PM-3AM) and irrigated directly from the IID canal. Such irrigation scheduling better represented the irrigation practices of commercial fields in the Valley. Except for a few occasions when the IID canal water ran dry during an irrigation event, we had complete control of when to turn the water on or off to the field.

Thirty-two 9-ft neutron probe access tubes were installed in each field (eight neutron probe access tubes were installed in each border). The probes were used to characterize soil moisture distribution in each field. Moisture measurements were taken at depths of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0, 8.0, and 9.0 ft prior to and 48-72 hours following each irrigation. Gravimetric soil moisture samples were taken in the 0-6" depth range because the neutron scattering technique does not accurately estimate soil moisture content near the surface. Evapotranspiration during and for the two or three days following irrigations were obtained from CIMIS weather station No. 87 and was added to the difference in soil moisture prior to and following each irrigation. Thirty-two 10-ft deep observation wells were installed in each field. The observation wells were used to determine water table elevation and to extract water samples from the shallow groundwater. Water samples from each well were taken for determination of salinity and Cl concentrations. Soil samples from the 32 locations in each field were taken at various depths (0-108") and times to evaluate the temporal and spatial distribution of soil salinity.

Soil preparation, planting rates, varieties, fertilization, and pest control were preformed according to the UCCE guidelines to production and practices for Imperial County-Field Crops (UCCE Circular 104-F) and alfalfa production in the low desert valley areas of California (UC DANR leaflet 21097). Alfalfa was cut at approximately 10% bloom. Hay was baled at moisture contents of approximately 10-15%. Except for irrigation management, alfalfa and sudangrass cultural practices used for this study followed the normal agricultural practices at UCDREC and were presumably typical of that found in the Valley.

Water conservation and management was the focus of this work and the primary changes to water management from that typical in the Valley included the following:

- Control of the duration of irrigation to ensure that the runoff water is minimized or eliminated (alfalfa and sudangrass fields).
- Reduce the frequency of application to utilize the shallow ground water (alfalfa field).

After the termination of the study, corn was planted on the alfalfa field in February 1999 and harvested in June 1999 to address the impact of this method on soil salinity and yield of a subsequent crop.

According to UCCE guidelines to production and practices (Mayberry et al., 1996), approximately 6.5 ac-ft/ac of water are used annually on alfalfa in the Imperial Valley (approximately 16 irrigations per year). The average application per irrigation is approximately 5 inches. Approximately ½ ac-ft/ac of water is used for land preparation and approximately another ½ ac-ft/ac is used for leaching. One to three irrigations per cutting are necessary depending on the soil type and time of the year (Mayberry et al., 1996). On clay soils, it is recommended to cut off the irrigation water when it is about 80% down the length of the field (Mayberry et al., 1996) to avoid crop scalding during late summer periods. Average water use on sudangrass in the Imperial Valley is approximately 4.8 ac-ft/ac (Mayberry et al., 1996). The salinity of Colorado River water is approximately 1.05-1.10 dS/m. Approximately ½ ton of salt per acre is added to the root zone in a typical irrigation. Leaching irrigations after crop termination are common and necessary to maintain a rootzone salt balance in Imperial Valley fields.

Brad fia is this true?

In 1998, field crops accounted for almost 80% of the 500,000 acres of irrigated land in the Imperial Valley. Alfalfa and sudangrass water use accounts for more than 50% of the total crop water use in the Imperial Valley (Tables 9 & 10).

Table 9. Alfalfa production in the Imperial valley

Year	Acres	Tons/ac	Value $/ton
1995	182,401	7.88	87.98
1996	161,116	7.56	101.84
1997	165,922	7.56	117.91
1998	178,517	7.65	93.64

Source: 1995-1998 Imperial County Agricultural Crop & Livestock reports

Table 10. Sudangrass production in the Imperial valley

Year	Acres	Tons/ac	Value $/ton
1995	77,365	6.50	85.00
1996	85,896	6.36	86.33
1997	87,562	5.56	98.77
1998	70,068	4.91	99.37

Source: 1995-1998 Imperial County Agricultural Crop & Livestock reports

4. Results and Discussion

4.1 Soil type:

According to Zimmerman (1981), Area 80 (alfalfa field) consists of soil types 106 (Glenbar clay loam), 110 (Holtville silty clay), and 115 (Glenbar silty clay loams) while Area 70 (sudangrass field) consists of soil types 114 (Imperial silty clay) and 115 (Glenbar silty clay loams). The published water-holding characteristics of the above soils are summarized in Table 11.

How do the published value compare with the actual values.

Table 11. Water holding characteristics of soils in areas 70 and 80 of UCDREC.

Soil type	Maximum depth (in)	Available water (in/in) --- depth (inches) --- 0-24	24-48	48+
Alfalfa field				
Glenbar 106 & 115	60	0.20	0.20	0.20
Holtville 110	60	0.21	0.14	0.09
Sudangrass field				
Imperial 114	60	0.21	0.21	0.21
Glenbar 115	60	0.20	0.20	0.20

These are published values where are actual characteristics? How come these aren't shown. Nuetron probe work should show some values.

Allowable depletion: 50% for most crops,
50-65% for crops that are relatively insensitive to water stress.

*Source: Water-Holding Characteristics of California soils- University of California, DANR Leaflet 21463.

Alfalfa = Holtv : Glenbar
Sudan = Imperial ; Glenbar

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Data presented in this report are preliminary *and not for publication* until authorized by the investigators – December 1999

The soils of the field used for the alfalfa trials were classified as Glenbar clay loam (moderately slow permeability and very high water available water capacity); Holtville silty clay loam (slow permeability in the clayey and moderately rapid in the underlying material, high to very high available water capacity) and Glenbar silty clay loams (moderately slow permeability and very high available water capacity). The soils of the fields used for the sudangrass trials were classified as Imperial silty clay (slow permeability and very high available water capacity) and Glenbar silty clay loams (moderately slow permeability and very high available water capacity).

According to Zimmerman (1981), the soils of the fields selected for the trials are representative of those in the Valley as Imperial Glenbar silty clay loam is found on 21 % (203,659 acres) of the Valley, while Holtville silty clay is found on 7 % (70,547 acres), Imperial silty clay on 12.5% (123,401 acres), and Glenbar clay loam on 0.4% (4,239 acres). Forty-eight soil samples were collected from 8 locations in the alfalfa field. The average clay content and soil texture classification of these soil samples are summarized in Table 12.

The soil in Area 70 is characterized by approximately 6 ft of relatively uniform silty clay to clay surface soil with montmorrilonic clay contents ranging from 50 to 70% (Grismer and Tod, 1994 and Grismer and Bali, 1997). The average clay content and soil texture of soil samples collected by Dr. Frank Robinson (UCDREC) from Area 70 are presented in Table 13.

Table 12. Soil texture classification and clay content of the alfalfa field.

Depth (in)	Clay content* (%)	Texture*	Clay range (%)	Texture range**
Surface	60	Clay	55-63	6 Clay, 1 SC, 1 SCL
6	59	Clay	55-63	7 Clay, 1 SC
12	58	Clay	47-65	8 Clay
24	59	Clay	55-65	8 Clay
36	48	Clay	19-67	6 Clay, 1 SL, 1 SNC
48	38	Clay loam	27-49	2 Clay, 3 CL, 1 SC, 2 SNCL

*Average of 8 locations (48 samples).
**SC: Silty clay, SCL: Silty clay loam, SL: Silt loam, SNC: Sandy clay, SNCL: Sandy clay loam.

Table 13. Soil texture classification and clay content of the sudangrass field.

Depth (in)	Clay content* (%)	Texture*	Clay range (%)
0-12	52	Clay	40-59
12-24	58	Clay	48-68
24-36	61	Clay	40-72
36-48	67	Clay	62-77
48-60	69	Clay	64-76

*Average of 10 locations (50 samples)
Source: Dr. F. Robinson, UCDREC

4.2 Sudangrass field cultural practices

Does not look like field was leached prior to planting. Might explain high EC values in Fig. 16. If not leached, unfair to compare to other Figures or to draw conclusion about dropping salinity. How long was field idle before study? Previous crop? etc.

1996 Season: Sudangrass (cv. 'Piper') was planted on April 15, 1996.
1997 Season: Sudangrass (cv. 'Piper') was planted on April 18, 1997.
1998 Season: Sudangrass (cv. 'Piper') was planted on April 14, 1998.
Seeding rates: following the standard practices for uniform crops at UCDREC.
Fertilizer: following the standard practices for uniform crops at UCDREC.
Pest control and harvesting: following the normal practices for uniform crops at UCDREC.

4.2.1 Irrigation dates and average depth of application

The irrigation turnouts (concrete pipes connecting the irrigation supply canal to field borders) at UCDREC were calibrated to establish a head-discharge relationship (Tod et al., 1991). The amount of water applied to each border was then measured using the method of Tod et al. (1991). Water-pressure head losses across the irrigation turnouts were measured on gages located at the downstream end of the irrigation turnouts. Measurements were taken approximately every 30 minutes during irrigation events. Plate valves that control flow through the turnout pipes were removed completely during irrigations.

Average onflow rate and depth of water application were determined for each irrigation and this data is given in Tables 14-16. Overall irrigation frequency and applied water (AW) depths as well as total number of cuttings for the sudangrass are summarized in Table 17.

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Table 14. Irrigation information (sudangrass field) - 1996 season

Irrigation Date	Average Depth of AW (in)	ET_o (in) since previous irrigation	Rain (in) since previous irrigation	(AW+Rain) /ET_o	Surface Runoff (% of AW)	Cutoff distance (ft)	% of field irrigated
1-18-96 (pre-irrigation)	3.87	Pre-irrigation	Pre-irrigation	Pre-irrigation	-	*	-
4-16-96	3.95	First irrigation	First irrigation	First irrigation	1	1132	99
5-3-96	2.84	5.04	0.00	0.56	1	959	98
5-24-96	5.08	7.57	0.00	0.67	0	874	95
6-28-96	6.92	11.51	0.00	0.60	0	908	89
7-23-96	5.72	7.87	0.00	0.73	0	862	93
8-20-96	6.94	8.43	0.00	0.82	0	868	97
9-17-96	6.05	7.40	0.00	0.82	0	860	100
Totals or Averages (4/16 to 10/10/96)	**37.50** (3.13 ac-ft/ac)	**53.40**	**0.00**	**0.70**	**0**	**923** (889 w/o 1st irrg.)	**96**

once/month irrigations

* Avg. cutoff distance 1150 ft (Runoff reduction method was not used for the pre-irrigation)

Table 15. Irrigation information (sudangrass field) - 1997 season

Irrigation Date	Average Depth of AW (in)	ET_o (in) since previous irrigation	Rain (in) since previous irrigation	(AW+Rain) /ET_o	Surface Runoff (% of AW)	Cutoff distance (ft)	% of field irrigated
4-21-97	5.69	First irrigation	First irrigation	First irrigation	0	992	95
5-5-97	1.73	4.12	0.00	0.42	2	797	99
6-2-97	7.42	8.48	0.00	0.88	0	881	87
6-20-97	5.35	5.63	0.00	0.95	3	921	100
7-9-97	5.70	6.50	0.00	0.88	3	888	100
7-29-97	5.18	5.64	0.00	0.92	4	874	100
8-20-97	6.04	6.40	0.00	0.94	3	856	100

9-10-97	5.47	4.98	0.16	1.13	4	873	100
10-10-97	3.63	5.82	1.02	0.80	4	853	100
Totals or Averages (4/21 to 11/25/97	**46.21** (3.85 ac-ft/ac)	**53.83**	**1.18**	**0.88**	**3**	**882** (868 w/o 1" irrg.)	**98**

Table 16. Irrigation information (sudangrass field) - 1998 season

Irrigation Date	Average Depth of AW (in)	ET_o (in) since previous irrigation	Rain (in) since previous irrigation	(AW+Rain) /ET_o	Surface Runoff (% of AW)	Cutoff distance (ft)	% of field irrigated
4-15-98	5.49	First irrigation	First irrigation	First irrigation	1	1062	99
4-22-98	2.28	1.74	0.00	1.30	0	836	98
5-20-98	5.53	7.59	0.00	0.72	4	918	100
6-17-98	6.04	8.31	0.00	0.73	2	957	100
7-8-98	5.77	6.77	0.00	0.85	2	850	100
7-29-98	5.54	6.03	0.04	0.92	4	843	100
8-20-98	4.59	5.88	0.12	0.78	0	700	91
Totals or Averages (4/15 to 9/8/98)	**35.24** (2.94 ac-ft/ac)	**41.20**	**0.16**	**0.86**	**2**	**881** (851 w/o 1" irrg.)	**98**

Table 17. Depths of water applied and number of cuttings for the sudangrass field.

Year	No. of irrigations	Total AW (in)	AW depth (in)	No. of cuttings
1996	7	41.37*	5.17	3
1997	9	46.21	5.13	3
1998	7	35.24	5.03	2

* includes pre-irrigation
Leaching irrigation: 6.20 inches

After the termination of crop production, the sudangrass field was disked and subsoiled according to the standard practices at UCDREC. A leaching irrigation was conducted in December 1998 where an average depth of 6.2 in. of water was applied. Leach Water compares Actual to general Averages. How would Mayberry's recommended value have worked under those conditions.

Implementation of the runoff reduction method requires that the user either determine the cutoff time or cutoff distance necessary to minimize runoff. Since it is easier for irrigators to use the cutoff distance rather time, the focus of our discussion here will be on the cutoff distance. With the exception of the first irrigation, the average cutoff distance in 1996 was 889 ft from the border's inlet or approximately 71% of the field's length (as compared to the maximum distance of 80% recommended by Mayberry et al,. 1996). We obtained no runoff at this cutoff distance and surface wetting reached 96% of the field length. In 1997 and 1998, the average cutoff distances for all irrigations except the first irrigation were 868 and 851 ft, respectively, resulting in surface wetting of 98% of the field. We found that the optimum cutoff distance to minimize or eliminate runoff varies from 850 to 950 ft or approximately 70 to 75% of the field's length. Our overall average cutoff distance was 870 ft or approximately 70% of the field's length (for all irrigations except first irrigations). The average cutoff distance for the first irrigations was larger (1062 ft or 85% of the field length) due to the newly-disked surface preparation of the field.

Except for the first irrigation, we found that cutting the applied water at approximately 75% of the field length resulted in sufficient water coverage to irrigate the entire border and have some runoff ranging from 1-4% of applied water. A cutoff distance of approximately 80-85% of the field's length is needed for the first irrigation to insure that enough water reaches the lower end of the field for seed germination. The method of Grismer and Tod (1994) may be used to estimate the volume of cracks and cutoff distance or time in heavy soils for all irrigations after the first irrigation in the growing season. Since cracks are not present prior to the first irrigation, the cutoff method should not be used on the first irrigation. Instead, we found the traditional two-point method (Elliott and Walker, 1982) could be used to estimate the cutoff distance for the first irrigation of the season. However, for simplicity, a cutoff distance of approximately 80-85% of the field length is recommended to ensure that enough water reaches the lower end of the field.

4.2.2 Average yields

Sudangrass was grown for three consecutive -growing seasons. After the first season, an oat crop was grown in Area 70 between December 1996 and February 1997 (a uniform cropping practice for UCDREC hay production). Sudangrass was harvested according to the normal practices of harvesting a uniform crop at UCDREC. Yields were measured by cutting and weighing the crop from representative samples areas along each border as well as by commercial harvesting methods. Average sudangrass yields reported in Tables 18-20 are based on weighing 10-15 sudangrass bales in the field after each cutting.

How were bales chosen? Headlands vs lower end?

12/1996 - 2/1997 Oats grown
- leach water prior to plant
- # irrigations
- water applied
- method used (i.e conventional means w/runoff?

12/1998 Leach water applied. = 6.2 inches

Table 18. Average sudangrass yield - 1996 growing season:

Cut date	Average yield (tons/acre)	Average yield (tons/acre) adjusted to 10% moisture
6-17—96	2.38	2.37
8-7-96	2.25	2.24
10-10-96	2.13	2.23
Total 1996	**6.76**	**6.84**

Table 19. Average sudangrass yield - 1997 growing season:

Cut date	Average yield (tons/acre)	Average yield (tons/acre) adjusted to 10% moisture
7-1-97	3.07	2.99
10-3-97	2.36	2.32
11-25-97	0.62	0.59
Total 1997	**6.05**	**5.90**

Table 20. Average sudangrass yield - 1998 growing season:

Cut date	Average yield (tons/acre)	Average yield (tons/acre) adjusted to 10% moisture
6-29-98	2.90	2.66
9-8-98	2.42	2.18
Total 1998	**5.32**	**4.84**

A water variability of 11 inches

The annual water use by the sudangrass between 1996 and 1998 ~~ranged~~ ranged from 35 inches to 46 inches. The average crop coefficients were 0.70, 0.88, and 0.86 in 1996, 1997, and 1998, respectively. We varied the irrigation frequency from seven irrigations per growing season in 1996 to nine irrigations per season in 1997 to evaluate the impact of varying irrigation frequency on applied water use efficiency (AWUE)of sudangrass (average yield per unit water applied). These results for sudangrass AWUE are presented in Table 21.

what is the accuracy of measuring moisture in ~~alfalfa~~ sudan? +/- 1-2%

Table 21. Sudangrass applied water use efficiency (tons per ac-ft/ac)

Cut number	Avg. depth of AW (inches)	Average yield (tons/acre) adjusted to 10% moisture	AWUE (tons per ac-ft/ac)	No. of irrigations/cut
1st cut 1996	11.87	2.37	2.40	3
2nd cut 1996	12.64	2.24	2.13	2
3rd cut 1996	12.99	2.23	2.06	2
1st cut 1997	20.19	2.99	1.78	4
2nd cut 1997	22.39	2.32	1.24	4
3rd cut 1997	3.63	0.59	1.95	1
1st cut 1998	19.34	2.66	1.65	4
2nd cut 1998	15.90	2.18	1.65	3
Total/*Avg.*	118.95	17.58	***1.77***	***3***

We obtained an overall average AWUE of 1.77 tons of sudangrass per ac-ft/ac of water applied. AWUE was greatest in 1996 and increased as the number of irrigations per cutting decreased. The average crop coefficient was greater in 1997 and 1998 than 1996, due to the greater evaporation rates from the wetter soils. The soil surface remains wet for several days while evaporation continues at the full rate due to the ability of the clay soil to retain moisture and remain saturated as its bulk density increases. Clay soils have the ability to remain fully saturated for 3-4 days following an irrigation event as soil bulk density increases to compensate for the lost water (evaporation). Therefore, AWUE is improved by reducing the irrigation frequency from four to three irrigations per first cutting and from three to two irrigations for the second and third cuttings. Moreover, the relatively high AWUE we obtained is also due to the fact that surface runoff was minimized (overall average runoff was approximately 2%).

4.2.3 Sudangrass hay quality

How were these selected?

Sixteen hay samples from bales harvested along the four borders were collected for hay quality determinations. Crude protein (CP) acid detergent fiber (ADF) and other hay quality parameters such as IVDMD and TDN ((AOAC, 1960, Goering and Van Soest, 1970 and Goering et al., 1973) were determined. The sudangrass hay quality parameters are presented in Figure 15. Crude protein and ADF are the most commonly used parameters to evaluate alfalfa and sudangrass hay quality. Both CP and ADF of the sudangrass hay samples at the lower end of the field were of similar quality to the samples collected from the upper end of the field suggesting that the hay quality across the field was not affected by the reduced runoff treatment. The overall quality of the sudangrass hay is typical of that grown at UCDREC.

quantify this term

Fig 15. shows hay quality better at lower end of field than upper end. Strange?

4.2.4 Soil salinity

Soil samples were collected from 32 measurement locations at depths to 108"prior to, during, and after the termination of the study (Figure 14). Soil samples were analyzed for salinity and Cl concentrations. Selected samples were also analyzed for other major ions (e.g. Na, Ca, Mg & Na). The average soil salinity distributions for the rootzone (upper 48") are shown in figures 16-21. These figures also show the average salinity distribution along the four sudangrass borders. In general, the salinity levels at 6 and 12-ich depth increments tend to increase from the head to the tail-end of the field. The increase in salinity at the lower end of the field is due to the surface leaching or lateral transport of salts from the soil surface and shallow soil depths (0-12") at the upper end of the field. Rhoades et al. (1997) found the same trend of relatively higher salinity at the tail end of heavy-textured fields in the Imperial Valley. Figure 22 summarizes changes in average soil salinity of the root zone profile at various times during and after the study. Average soil salinity levels ranged from 7.38 dS/m to 8.58 dS/m. The average salinity in the top 48" of the soil profile was the greatest (8.58 dS/m) at the beginning of the study in spring 1996. The average salinity at the end of the study and before the leaching irrigation was 7.90 dS/m which represents an 8% decline in salinity since the beginning of the study. The average salinity level declined further to 7.47 dS/m after leaching. This indicates that sufficient leaching occurred during the study and that the reduced runoff irrigation method did not have an adverse impact on soil salinity. Moreover, the leaching irrigation was not necessary at the end of the sudangrass season. Figure 23 illustrates the changes in soil salinity within the soil profile at various times during the study. Most of the leaching occurred in the top 24-36 inches of the soil profile. Figure 24 illustrates the changes in soil Cl concentration within the soil profile at various times and also clearly indicates that most of the leaching occurred in the top 24-36" of the soil profile. ?

4.2.5 Water table

Thirty-two 1-inch-diameter observation wells were installed in the field (Figure 14). Water table depth was monitored prior to and following irrigations. Water samples from the observation wells were analyzed for salinity and Cl concentrations. Average water table depth, salinity and Cl concentrations are presented in Figures 25-27. Water table elevation remained nearly constant in 1996. Water table elevation increased by 2-4" immediately following irrigations and both salinity and Cl concentration of the water table decreased as a result of irrigation. In 1997 and 1998, water table elevation increased from about 80" below ground level to about 60-65" below ground level during the cropping season. This indicates that sufficient water was available for adequate leaching. Except for short-term declines after irrigation events, both salinity and Cl concentration of the water table remained nearly constant during each growing season.

why? Influenced by adjacent activities? Result of test plot irrigations.

4.2.6 Impact of water table control on soil salinity and leaching

An independent experiment was conducted on three borders east of the sudangrass field to determine if water table control (lowering the water table from approximately 5-6 ft to a depth of 12–20 ft below the soil surface) is effective in reducing soil salinity and improving leaching in the rootzone. We utilized part of a skimming drainage well system that was installed in 1992 (Grismer and Bali 1997). The system consists of 26 2-inch diameter wells spaced 20 ft a part in a line along the middle of two borders (borders 1 and 2). Each well draws water from the water table from a depth of 12-20 ft and discharges it via a mainfold connected to a diaphragm pump to a surface drainage canal at the end of the field. The experiment was initiated in August 1996. The three borders were disked and border checks were placed around an area 62 ft wide by 128 ft long to hold water in border 2 during continuous ponding. Groundwater level, water content, and soil salinity were monitored regularly before, during and after the ponding experiment, both inside and outside the flooded area. Five monitoring sites were established, each site had an observation well, NP access tube, and soil sampling location. The pump was turned on in July 96 to lower the water table in and around the study area. In addition, the 62' by 128' area was flooded on Aug. 14 and the ponded water level maintained until Sep. 19 to evaluate continuous flooding leaching potential. Results from this work suggested that lowering the water table was effective in reducing soil water content and was useful in leaching reclamation of clay soils only after continuous surface ponding and groundwater pumping. The shallow drainage-well system alone was effective in controlling water table depth but had little effect on reducing rootzone soil salinity without surface ponding.

Where are results?

4.3 Alfalfa field

Was field leached prior to planting?

Alfalfa was planted on November 7, 1995 and the field was renovated and reseeded in October 1997. Seeding rates, fertilizer use, pest control and harvesting practices followed the standard procedures for uniform crops at UCDREC. Renovation and reseeding of alfalfa fields in heavy soils is a common practice in the Imperial Valley. Alfalfa stand loss in the Valley is common due to variety of causes such as high summer temperatures, high humidity, poor soils, plant damage, wheel tracks of farm equipment, and the ever-present plant diseases (Lehman, 1979). Weak stands of alfalfa on heavy soils may require annual reseeding (Zimmerman, 1981) as thick, uniform stands compete well with weeds and tend to result in higher yields during the first few cuttings (Lehman, 1979).

4.3.1 Irrigation dates and average depth of water application

The irrigation turnouts at UCDREC were calibrated as for the sudangrass field and the amount of water applied to each border was measured using the method of Tod et al. (1991) (see section 4.2.1). We followed the recommendations of Lehman (1979) regarding proper irrigation timing and application of water to minimize summer stand loss. Lehman's recommendation is to irrigate and manage alfalfa fields during August and September with stand survival as the primary concern. However, in this study our primary objective was to improve water use efficiency, or optimizing rather than maximizing yield. Average flow rate and average depth of application were determined for all irrigations (Table 22). Alfalfa irrigation practices and total number of cuttings are summarized in Table 23 for the entire duration of the project.

Farmer decision? Choice = max yield.

The average cutoff distance for the entire alfalfa growing period was 887 ft from the border's inlet or approximately 71% of the field's length. This is almost identical to the average cutoff distance of the sudangrass field. We obtained an average runoff of approximately 2% at this cutoff distance and managed to irrigate 99% of the field. Except for the two germination and stand establishment irrigations, the average cutoff distance varied from 797 to 940 ft or from 64 to 75% of the field's length. Flowrate and soil crack size were the main factors affecting the average cutoff distance. We found that the optimum cutoff distance to minimize or eliminate runoff varied from 800 to 950 ft or approximately 65 to 75% of the field's length.

?

Except for the first two germination and stand establishment irrigations, we found that cutting the water at approximately 75% of the field's length resulted in sufficient water coverage to irrigate the entire border and have some runoff ranging from 1-6% of applied water. A cutoff distance of approximately 85% of the field's length is needed for the first two irrigations to insure that enough water reaches the lower end of the field to germinate alfalfa. As noted for the sudangrass field, the method of Grismer and Tod (1994) may be used to estimate the volume of cracks in heavy soils for all irrigations except the first two irrigations. Since cracks are not present prior to the first two irrigations, the cutoff method should not be used. Instead, we found the traditional two-point method (Elliott and Walker, 1982) could be used to estimate the cutoff distance for the first two irrigations. However, for simplicity, a cutoff distance of approximately 85% of the field's length is recommended and is adequate to ensure that enough water reaches the lower end of the field.

Table 22. Irrigation information - Alfalfa field

Irrigation Date	Average Depth of AW (in)	ET_o (in) since previous irrigation	Rain (in) since previous irrigation	(AW+Rain) /ET_o	Surface Runoff (% of AW)	Cutoff distance (ft)	% of field irrigated
11-8-95	3.91	First irrigation	First irrigation	First irrigation	2	1115	99
12-4 & 12-5-95	3.53	2.50	0.00	1.41	7	1020	99
1-22 & 1-23-96	5.01	3.64	0.04	1.39	6	868	100
3-19-96	5.52	7.65	0.12	0.74	4	896	100
4-24-96	6.13	9.46	0.00	0.65	1	885	100
5-17-96	5.62	7.59	0.00	0.74	2	894	99
6-7-96	4.99	7.16	0.00	0.70	0	832	93
7-3-96	5.57	8.61	0.00	0.65	2	878	100
8-2-96	5.49	9.23	0.00	0.59	0	853	97
9-10-96	5.28	11.11	0.00	0.48	0	875	94
11-1-96	5.30	10.75	0.00	0.49	1	876	97
12-20-96	4.19	4.38	0.00	0.96	2	897	100
2-19-97	4.37	5.90	0.32	0.79	2	852	100
4-7-97	4.65	9.29	0.12	0.51	0	797	95
4-28-97	4.66	5.91	0.00	0.79	2	834	100
5-19-97	4.57	5.88	0.00	0.78	1	855	100
6-16-97	4.47	8.75	0.00	0.51	0	917	97
7-11-97	5.27	8.46	0.00	0.62	1	932	98
7-23-97*	1.42 (only two borders irrigated, 2.84")	3.20	0.00		1	798	100
8-8-97	4.80	4.85	0.00	0.99	3	940	100
8-19-97*	1.79 (only two borders irrigated, 3.58")	3.08	0.00		2	856	100
9-5-97	4.59	4.13	0.00	1.11	1	922	100

once A month irrigations

only 10" AWC in 4' R2 w/2.5"/ft available water ?

10-18-97	4.60	8.45	1.18	0.68	2	918	100
11-14-97	3.40	3.68	0.00	0.92	1	880	99
2-13-98	4.58	6.89	1.19	0.84	1	900	99
3-20-98	4.60	4.77	0.59	1.09	3	942	100
4-17-98	5.15	5.77	0.16	0.92	2	911	99
4-29-98	3.24	3.20	0.00	1.01	1	779	100
5-15-98	4.39	4.42	0.00	0.99	0	870	98
5-27-98	3.87	3.24	0.00	1.19	2	861	99
6-12-98	4.70	3.63	0.00	1.29	2	902	98
6-26-98	4.55	5.76	0.00	0.79	2	911	100
7-14-98	5.07	5.57	0.00	0.91	0	817	97
Totals or Averages (11/8/95 to 8/4/98)	**149.28** (12.44 ac-ft AW/ac)	**202.94**	**3.72**	**0.75** (w/o WTC) 0.84 (including WTC)	**2**	**887** (880 w/o 1st irrig.)	99

*Two out of four borders received extra irrigation on these dates at the request of the project advisory committee. The objective here was to evaluate the impact of two irrigation versus one irrigation per cutting on alfalfa yield. The average alfalfa yield on these two borders was 27 and 31% higher as compared to the other two borders that received one irrigation per cutting.

Table 23. Summary of the amount of water applied and number of cuttings for the alfalfa field.

Year	No. of irrigations	Total AW (in)	Avg. AW depth (in)	No. of cuttings
1995	2	7.44	3.72	Stand establishment
1996	10	53.10	5.31	8
1997	12[1]	48.59	4.42	8[2]
1998	9	40.15	4.46	7

1 irrig./cutting?

[1] Includes two irrigations where only 2 borders (out of 4) were irrigated (see previous table).
[2] One cutting lost due to insect damage.
Leaching irrigation: 6.06 inches.

4.3.2 Average yields

Alfalfa yields were measured by cutting and weighing the crop from representative samples areas along each border as well as by commercial harvesting methods. Average alfalfa yields reported in Table 24 are based on weighing alfalfa samples collected from 20' by 3' sections adjacent to NP locations.

Table 24. Average alfalfa yields.

Cut date	Average yield (tons/acre) dry matter	Average yield (tons/acre)adjusted to 10% moisture
3-4-96	1.23	1.35
4-17-96	1.25	1.38
5-28-96	1.70	1.87
6-24-96	1.77	1.95
7-24-96	1.29	1.42
8-27-96	0.87	0.96
10-15-96	0.82	0.90
12-9-96	0.62	0.68
2-4-97	0.59	0.65
3-27-97	Insect damage	Insect damage
5-7-97	1.20	1.32
6-5-97	1.19	1.31
7-7-97	0.92	1.01
8-1-97	0.95	1.05
8-29-97	0.86	0.95
10-7-97	0.60	0.66
1-21-98	0.56	0.62
3-10-98	0.70	0.77
4-10-98	0.83	0.91
5-8-98	1.10	1.21
6-8-98	1.18	1.30
7-6-98	1.19	1.31
8-4-98	0.45	0.50
Totals	**21.87**	**24.06**

The average alfalfa yield distributions along the border for each cutting are shown in Figures 28-32 based on yield measurements obtained at each of the 32 measurement locations. For selected cuttings, we obtained continuous yield measurements at 20 ft intervals along each border (approximately 230 yield measurements per cutting). The yield distributions along the field for one of these cuttings are shown in Figure 33. For most summer cuttings (June-September), alfalfa yield declines at the lower end of the field. The decline in alfalfa yield is due to a combination of reduced water application and high salinity (greater water table contributions) at the lower end of the field. The decline at the lower end of the field is less visible between October and May cuttings (Figure 34). The overall average yield loss due to yield reduction at the lower end of the field is approximately 1.5% of the expected yield of the entire field. However, under normal irrigation practices on heavy clay soils in the Imperial Valley, almost the entire alfalfa yield at the lower end of the field is commonly lost to scalding. One of the advantages of the runoff reduction method is our ability to maintain a good stand of alfalfa at the lower end of the field and prevent or minimize scalding.

Following alfalfa production, the field was disked and sweet corn was planted to assess the possible salinity impacts of the surface runoff reduction method on subsequent crops. Two sets of 32 samples of corn were taken in April and May 1999 from 3.3-ft furrow sections next to the 32 measurement locations. Corn dry matter distributions along the field are shown in Figure 35. Corn yield measurements were also obtained at each of the 32 measurement locations in June 1999. Corn dry matter and yield measurements at the lower end of the field were not significantly different from those obtained at the upper half of the field. As in the sudangrass field this result suggests that there was no adverse salinity accumulation in the field from the three years of the surface runoff reduction method of irrigation.

The average crop coefficient ((AW+rain+water table contribution, WTC)/ET_o)) for the entire alfalfa growing season was 0.84. The WTC component is discussed in detail below (Section 4.3.7). We varied the irrigation frequency from one to two irrigations/per cutting to maximize the upward movement of water from the water table to the root zone. Utilizing the water table, reducing irrigation frequency, and minimizing surface runoff maximized our alfalfa water use (WUE) efficiency figures where WUE is defined as the dry tons of alfalfa yield obtained per unit water use (including AW, WTC, and rain). Our overall average WUE was 1.54 dry tons of alfalfa per ac-ft/ac of water used and the AWUE (i.e. Yield/AW) was 1.76 dry tons of alfalfa per ac-ft/ac. WUE's for each cutting can be calculated from the water use and yield values presented in the previous tables. As noted by Lehman (1979), we generally obtained the maximum WUE in late winter and early spring cuttings.

4.3.3 Alfalfa hay quality

Sixteen hay samples from bales harvested along the four borders were collected for determination of hay quality parameters. Crude protein (CP) acid detergent fiber (ADF) were measured. The results of the alfalfa hay quality analyses are shown in Figure 36. Both CP and ADF of the alfalfa hay samples at the lower end of the field were of similar quality to the samples collected from the upper end of the field. This indicates that the hay quality at the lower end of the field was not affected by the reduced runoff treatment. The overall quality of the alfalfa hay is typical of uniform alfalfa hay quality grown at UCDREC.

4.3.4 Soil salinity

Soil samples were collected from 32 measurement locations at depths to 108"prior to, during, and after the termination of the study (Figure 14). Soil samples were analyzed for salinity and Cl concentrations. Selected samples were also analyzed for other major ions (e.g. Na, Ca, Mg & Na). The average soil salinity distributions for the rootzone (upper 48") between November 1995 and May 1999 are shown in Figures 37-44. The figures also show the average salinity distribution along the four alfalfa borders. In general, the salinity levels at 36" and 48" depth increments tended to increase from the head to the tail-end of the field. The increase in salinity at the lower end of the field is most likely due to the upward movement of water from the water table. Soil of the lower half of the profile has relatively lower clay contents than the upper half (see Table 12) and therefore has a higher hydraulic conductivity which enables greater rates of upward movement of water within the lower half of the soil profile. Unlike the Sudangrass field, surface leaching or lateral transport of salts from the soil surface and shallow soil depths (0-12") at the upper end of the field was not observed until August 1998. Lateral transport of salts was evident after the leaching irrigation (Figure 43).

Figure 45 summarizes changes in average soil salinity of the root zone profile between November 1995 and May 1999. Despite the increase in average soil salinity during the alfalfa growing period, soil salinity levels after one leaching irrigation and planting and irrigating sweet corn returned to salinity levels at or below pre-study levels (Figs. 45 and 46). The average salinity of the soil profile (0-108") for various dates is shown in Fig. 47. Little change in soil salinity occurred at the upper half of the soil profile (0-24") during or after the study. Most of the changes occurred at depths below 24 inches due to the upward movement of water from the water table. It is clear that most of the soil salinity changes occurred between January 1996 and March 1997. We found this to be strongly correlated to water table contribution figures where most of the water table contribution occurred during the first year of the study. Average chloride concentrations within the soil profile also indicated that most of the water table contribution occurred during the first year of the study (Fig. 48).

4.3.5 Water table

Thirty-two 1-inch-diameter observation wells were installed in the field (Figure 14). Water table depth was monitored prior to and following irrigations. Water samples from the observation wells were analyzed for salinity and Cl concentrations. Average water table depth, salinity and Cl concentrations are shown in Figure 49. Water table elevation was relatively high at the beginning of the study (55-65" below ground level) then declined to about 75-80' during the first summer. Water table decline in the first summer and an accompanied increase in soil salinity at levels at below 36" clearly indicates that water table contribution to crop water use was significant during the first year of the study. In general water table elevation declined in summer months of 1997 and 1998 but didn't reach the depths occurring the previous summer (1996). In general, water table elevation increased by 2-4" immediately following irrigations and both salinity and Cl concentration of the water table decreased as a result of irrigations. Except for short term declines after irrigation events, both salinity and Cl concentration of the water table remained nearly constant during the study (Fig. 49).

4.3.6 Impact of water table control on salinity and water table level

The drainage system of Area 80 (approximately 36 acres) is composed of nine diagonally-oriented 4"-diameter tile drains on a 150-ft spacing. The laterals drain to an 8"-diameter collector line in the northeast section of Area 80. The subsurface drainage system was blocked at an access manhole to the eastern-most lateral drain and the drainage collector junction in August 1994 and remained blocked for the duration of the alfalfa growing season. In addition to the 32 observation wells that were installed in the alfalfa field, an additional south-north transect of observation wells were installed along the east side of Area 80. Water table levels in this transect were measured on the day the drain was plugged and at intervals of 4 to 21 days after plugging the system. Water table levels in the main alfalfa field were measured prior to and after each irrigation. Water samples from all observation wells were collected at the time of water table measurements. The samples were analyzed for salinity and chloride.

This particular aspect of the study was conducted in conjunction with a larger study to evaluate the effectiveness of subsurface drainage systems at UCDREC (Grismer and Bali, 1998). We had expected to see a gradual rise in water table levels, groundwater salinity Cl concentration due to the addition of irrigation water to the system. After three years of monitoring, we found that average water table levels followed a seasonal variation that reflected the frequency of irrigation. Salinity and chloride concentrations in the south-north transect remained nearly constant. It appears that the presence of deep drainage ditches combined with the shallow fine-sand aquifer below UCDREC controlled groundwater levels below Area 80 and the Meloland area as a whole. We found that plugging the drains to raise water levels to increase the utilization of groundwater contribution for crop evapotranspiration (ET) was of limited effectiveness as a result. Water table contributions to crop ET was also limited due to the high salinity of drainage water and the water retention properties of the clay soils in Area 80. The soil hydraulic properties limited the upward movement of water from the water table to the active rootzone. Details of our efforts to evaluate the effectiveness of drainage systems in clay soils are presented in *California Agriculture* (Grismer and Bali, 1998).

4.3.7 Water table contribution

Water table contributions (WTC) to crop ET depend on the soil hydraulic properties, ET demand, distribution of the crop root system, water table depth, and the salinity of groundwater. We used the mass flow method (Wallender et al. 1979) to estimate the contribution of water table to the evapotranspiration of alfalfa using chloride present in the water table as a tracer to quantify the upward movement of water from the water table to the root zone. We determined the Cl concentration for each 12-inch depth increment of the soil profile in the rootzone (48 inches) at the soil measurement locations in the alfalfa field. Chloride levels in soil, water table, and irrigation water were determined prior to alfalfa planting, five times during the alfalfa growing period, and after leaching. We estimated a maximum water contribution of 12.27 inches between the period of November 1995 and November 1996. During this same period, we applied 56.35 inches of irrigation water (ET_o=79.89 inches). We estimated a maximum water table contribution of 5.3 inches between the period of March 97 and October 1997. During this period we applied 36.22 inches of irrigation water (ET_o=53.55 inches). Water table contributions between November 1996 and March 1997 were negative (i.e. leaching). Water table contributions after October 1997 were also negative. Most of the water table contribution to alfalfa water use occurred during the first year of the study. Maximum water table contributions for various soil depth increments are presented in Table 25.

Table 25. Maximum water table contributions in the alfalfa field.

Depth interval (in)	11/95 - 11/96	11/96 - 3/97	3/97 - 10/97	10/97 - 8/98	Total
0-24	<leaching>		<leaching>		<leaching>
24-36	5.47		2.24		7.71
36-48	6.80		3.06		9.86
Total (0-48)	**12.27**	<leaching>	**5.30**	<leaching>	**17.57**

Total WTC for the entire alfalfa cropping period was less than 18" as compared to the 149" of AW. Approximately 70% of this WTC occurred during the first year of the study. As a result, the salinity of the lower soil profile (36-48) increased to the maximum salinity levels that could be tolerated by alfalfa. Most of the upward water movement was limited to the lower 25% of the root zone profile (36-48"). Most of the alfalfa roots were in the upper 36 inches of the root zone profile (Figure 50). Very little roots were found at depths below 36". However, roots below 36"were found at the lower end of the field suggesting that greater upward water movement occurred at the lower end of the field as compared to the upper end of the field. This observation of root distribution in the soil corresponded well to the observed chloride concentrations at the lower end of the field as noted earlier.

5. Educational Activities

PAC Meetings:

Nov. 1994 DWR/IID tour & presentation
Jan.- Aug. 1995 Draft proposals UCCE/IID

Sep. 1995. First PAC meeting (UC/IID/DWR/USBR)
Nov. 1995 Alfalfa planting
Nov. 1995 UCCE/IID (commercial fields meetings)
Nov. 1995- Nov. 1997 UCCE/IID (commercial fields)
Jan. 1997 second PAC meeting (UC/IID/DWR/USBR)
Jan. 1997 IID-Water Conservation Advisory Board (WCAB) presentation
May 1997 third PAC meeting (UC/IID/DWR/USBR)
Nov. 1997 (10 commercial fields selected)
Dec. 1997 fourth PAC meeting & Comm. field tour (UC/IID/DWR/USBR)
May 1998 fifth PAC meeting (UC/IID/DWR/USBR)
June 1998 WCAB presentation
May 1999 Conf. & sixth PAC meeting

Educational activities:

1997 Two Presentations- Water Conservation Advisory Board (January and April, 97)
1998 UCDREC Alfalfa Field Day
1998 Presentation- Water Conservation Advisory Board (June 98)
1998 Irrigation Workshop (June 98)
1998 CIMIS Workshop-Blythe
1998 CIMIS Workshop-Holtville (June 98)
1998 Salinity Workshop (Nov. 98)
1999 Internet Workshop -CIMIS (March 99)
1999 Irrigation Management & Surface Runoff Reduction Conference (May 19-20, 99)
1995-1998 Eleven field visits (local farmers, IV press, IID, students, consultants)
1996-1999 Three UCDREC Alfalfa Field Days

Computer program and spreadsheet files (please see section I)
Best Management Practices for Runoff Reduction in Clay Soils (Please see section I)

Objectives accomplished were presented to the Project advisory Committee on May, 21, 1998 and May 19, 1999.

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- Land & Labor provided by UCDREC.
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- We greatly appreciate the contributions made by the project advisory committee (UC, IID, DWR, USBR, NRCS, growers).

6. Conclusions

A significant amount of runoff water was saved as a result of the implementation of the surface runoff reduction irrigation method. Only 2% of applied water was lost to runoff. Water application efficiency was greatly improved by reducing the volume of surface runoff water. Additional water savings were obtained by reducing the frequency of water application from two to one irrigation per alfalfa cutting cycle. The effect of reduced surface runoff irrigations on alfalfa yield was only minimal (less than 2% reduction). Sudangrass yield was not affected by the surface runoff reduction treatment which resulted in significant water savings. Alfalfa and sudangrass hay quality was not affected by the implementation of the runoff reduction method. We obtained average water use efficiencies of 1.77 tons of sudangrass per ac-ft/ac and 1.54 dry tons of alfalfa per ac-ft/ac.

We found that cutting the water at approximately 70-75% of the field's length resulted in sufficient water coverage to irrigate the entire border and reduce runoff to from 1-6% of the applied water. For the first irrigation, a cutoff distance of approximately 80-85% of the field's length is recommended and adequate to ensure that enough water reaches the lower end of the field. The method of Grismer and Tod (1994) may be used to estimate the volume of cracks and cutoff distance or time in heavy soils for all irrigations after the first irrigation in the growing season.

Water table contribution (WTC) to alfalfa crop evapotranspiration was only significant during the first year of the study. Water table contribution accounted for approximately 18% of alfalfa crop water use during the first year of the study and only 11% during the entire alfalfa growing period (Nov. 95 through Aug. 98). The average alfalfa crop coefficient for the entire alfalfa growing period was approximately 0.84. The average crop coefficient for the sudangrass field for all three growing seasons was approximately 0.81.
Kc

An increase in soil salinity at the lower end of the alfalfa field was observed as a result of the upward movement of water from the saline water table. However, soil salinity levels after leaching and planting a salt sensitive crop (sweet corn) were at or below salinity levels at the beginning of the experiment. Soil salinity in the sudangrass field did not increase as a result of the implementation of the runoff reduction irrigation method. why?

Additional work is needed to verify the applicability of this method to commercial-size fields and under conditions where irrigation water deliveries are set for either 12 or 24-hour orders as is the case in the Imperial Valley.

7. References

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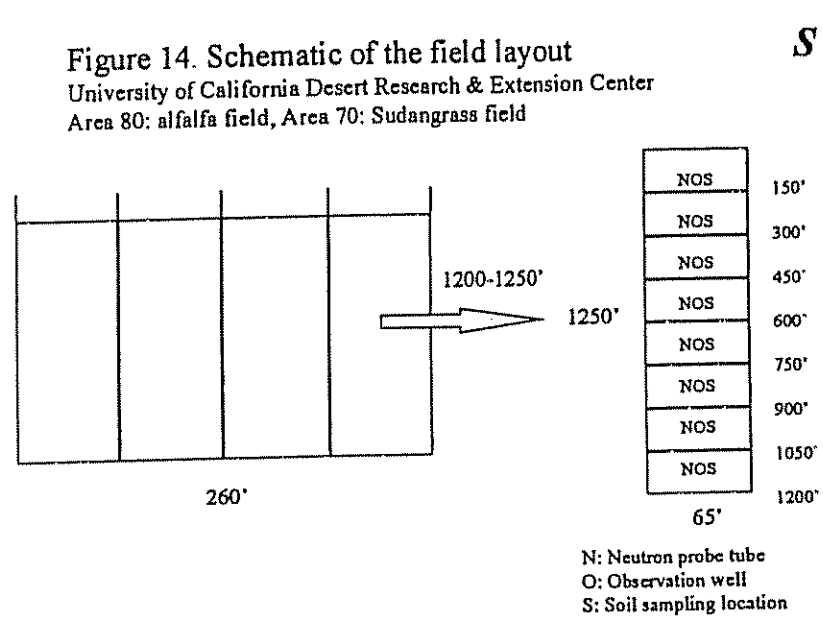
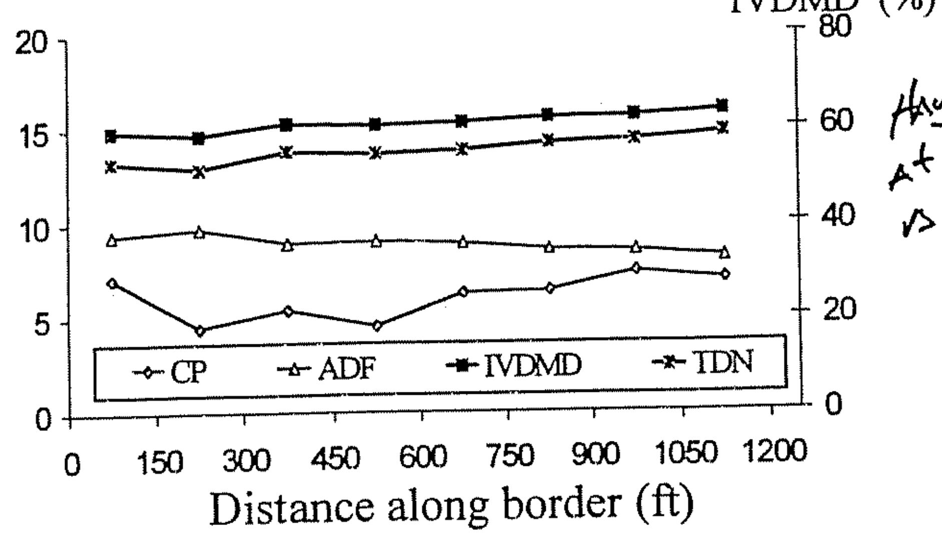
Figures 14-50

Figure 14. Schematic of the field layout
University of California Desert Research & Extension Center
Area 80: alfalfa field, Area 70: Sudangrass field



Map not to scale

Figure 15. Sudangrass hay quality parameters (July 1997)



Hay quality "better" at lower end vs upper end

Figure 16. Average Soil Salinity Profiles Along Sudangrass Field, March 1996

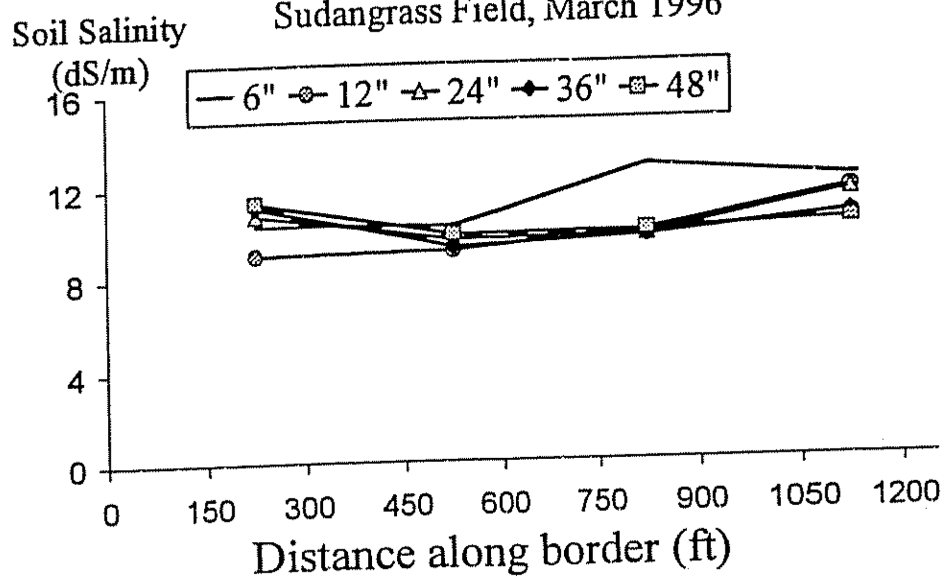
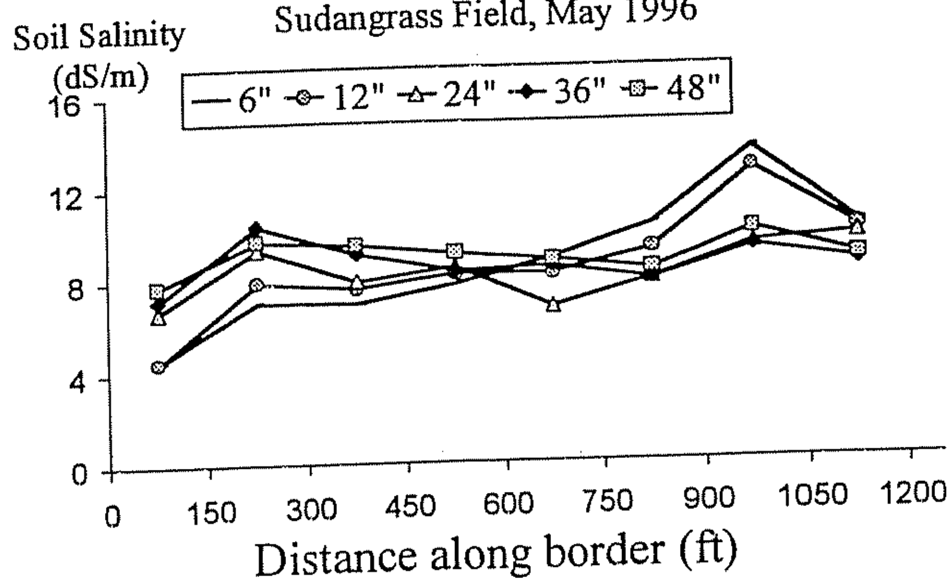


Figure 17. Average Soil Salinity Profiles Along Sudangrass Field, May 1996



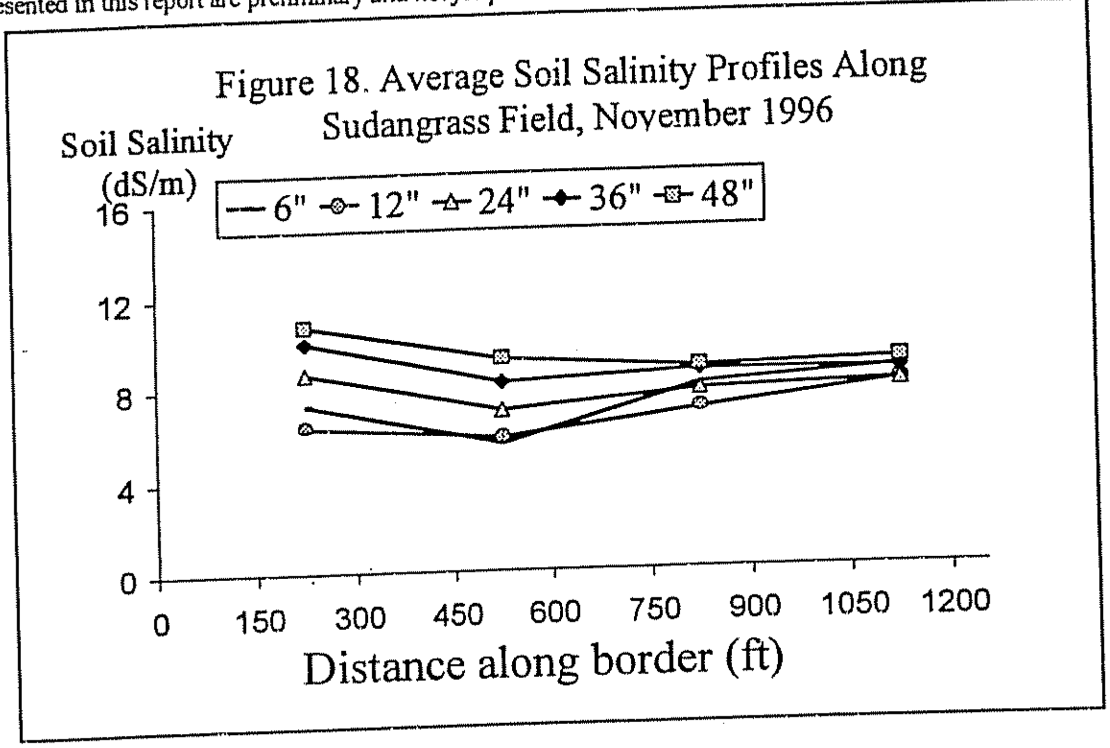


Figure 18. Average Soil Salinity Profiles Along Sudangrass Field, November 1996
Soil Salinity (dS/m)
6" 12" 24" 36" 48"
16
12
8
4
0
0
150
300
450
600
750
900
1050
1200
Distance along border (ft)

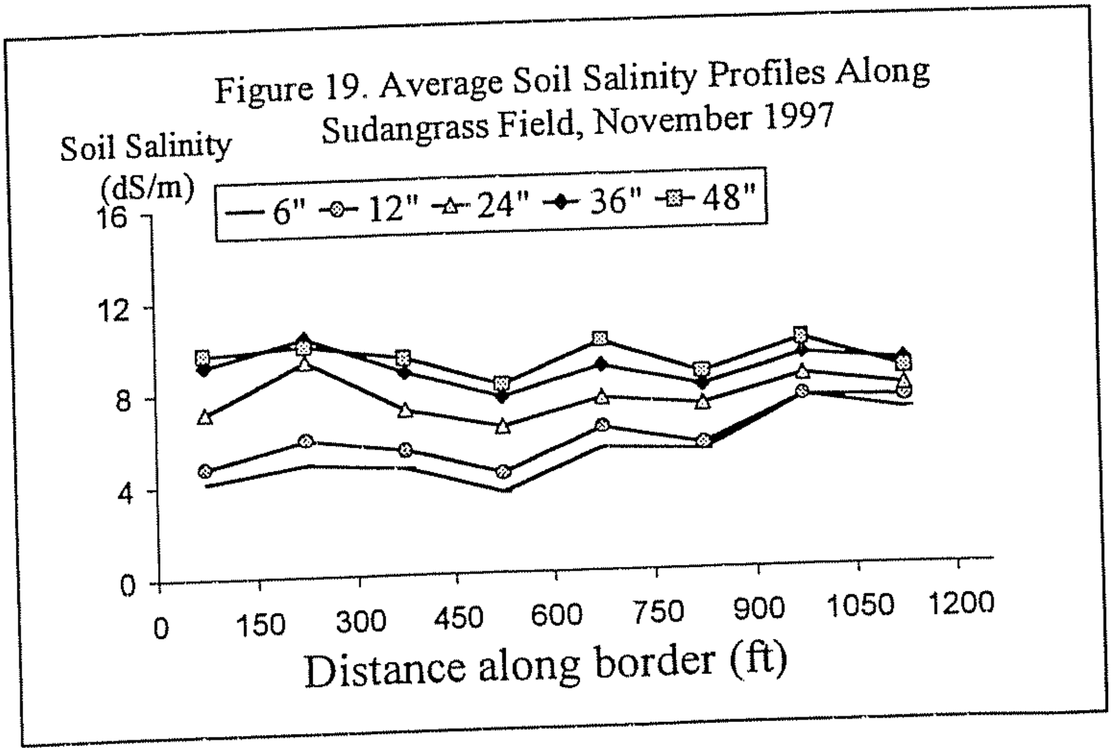


Figure 19. Average Soil Salinity Profiles Along Sudangrass Field, November 1997
Soil Salinity (dS/m)
6" 12" 24" 36" 48"
16
12
8
4
0
0
150
300
450
600
750
900
1050
1200
Distance along border (ft)

Figure 20. Average Soil Salinity Profiles Along Sudangrass Field, September 1998

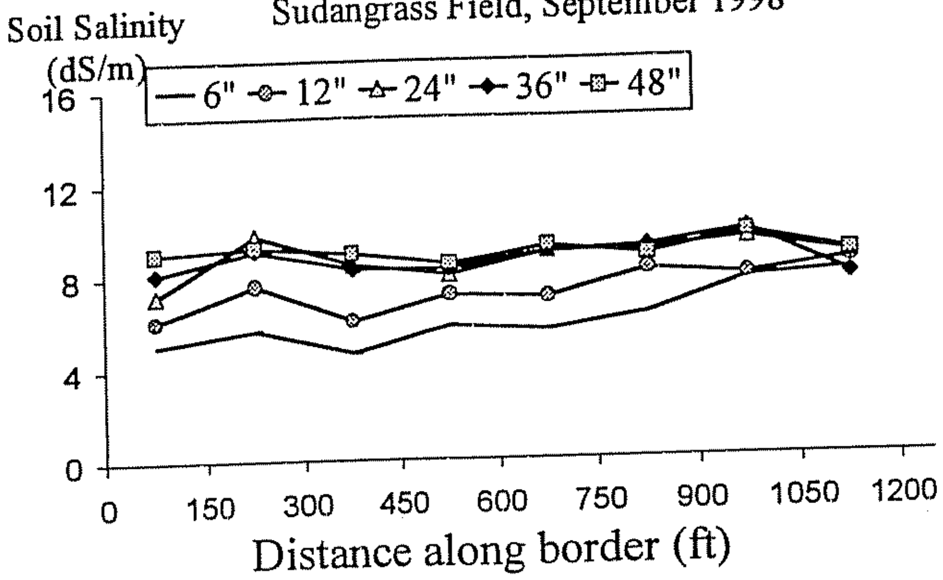
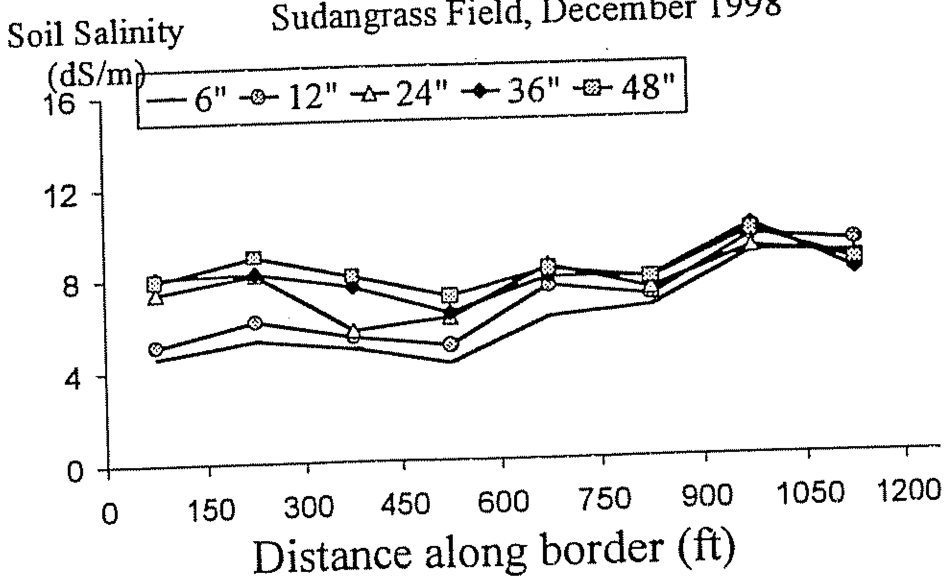


Figure 21. Average Soil Salinity Profiles Along Sudangrass Field, December 1998



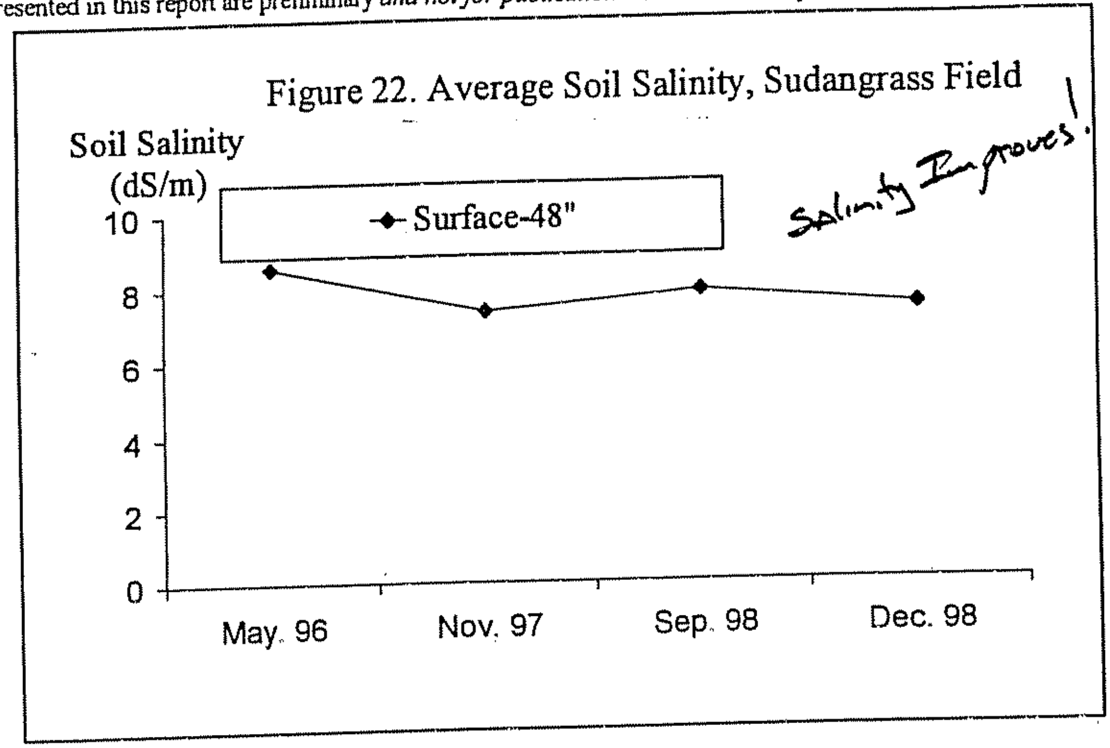


Figure 22. Average Soil Salinity, Sudangrass Field
Soil Salinity (dS/m)
Surface-48"
0
2
4
6
8
10
May. 96
Nov. 97
Sep. 98
Dec. 98
Salinity Improves!

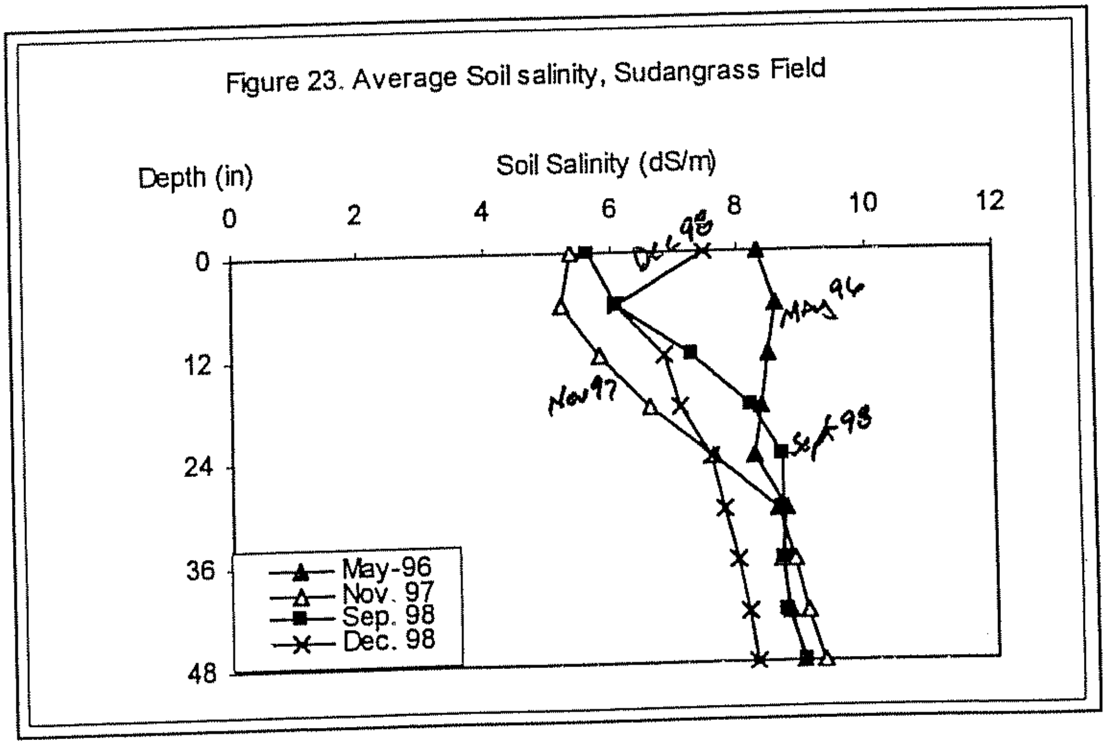


Figure 23. Average Soil salinity, Sudangrass Field
Depth (in)
Soil Salinity (dS/m)
0
2
4
6
8
10
12
0
12
24
36
48
May-96
Nov. 97
Sep. 98
Dec. 98
Dec 98
May 96
Nov 97
Sep 98

Figure 24. Average Cl Concentration, Sudangrass Field

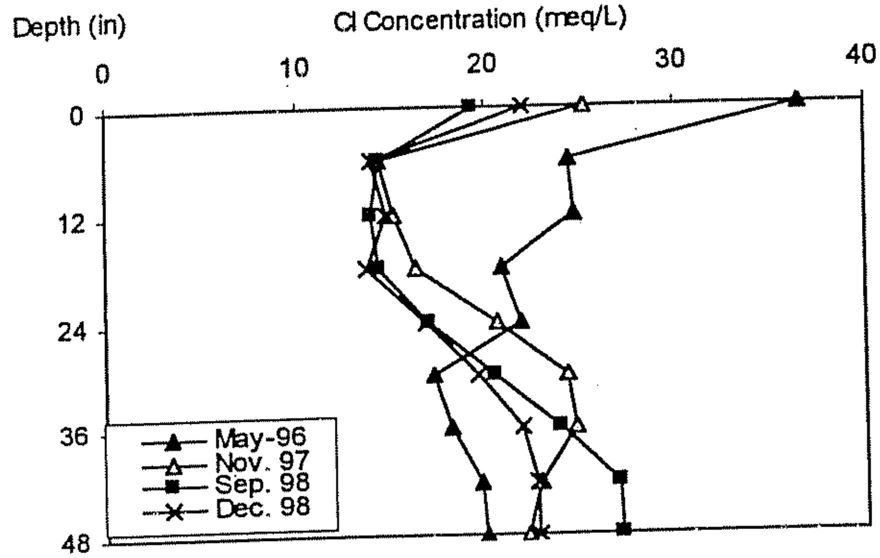


Figure 25. Water table elevation and salinity, Area 70 sudangrass field. 1996

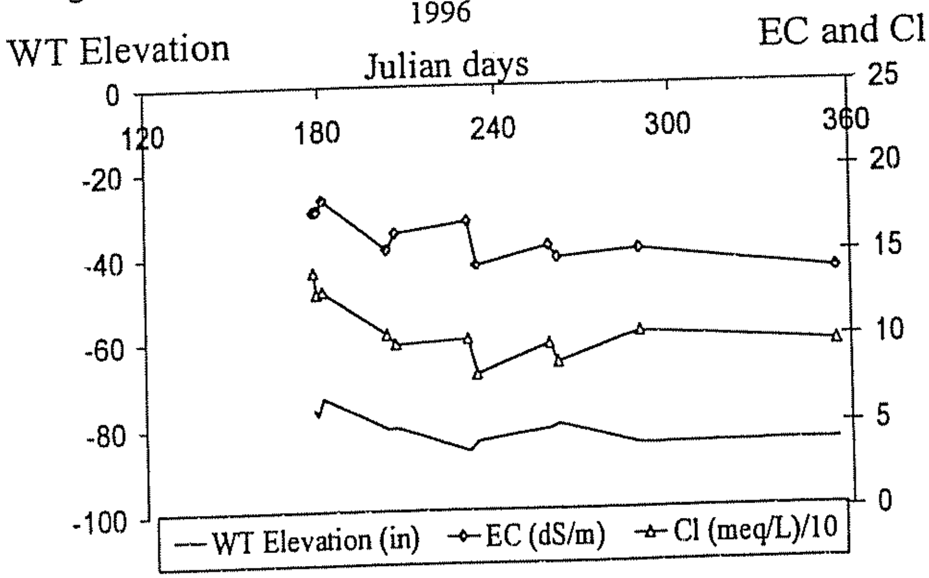


Figure 26. Water table elevation and salinity, Area 70 sudangrass field. 1997

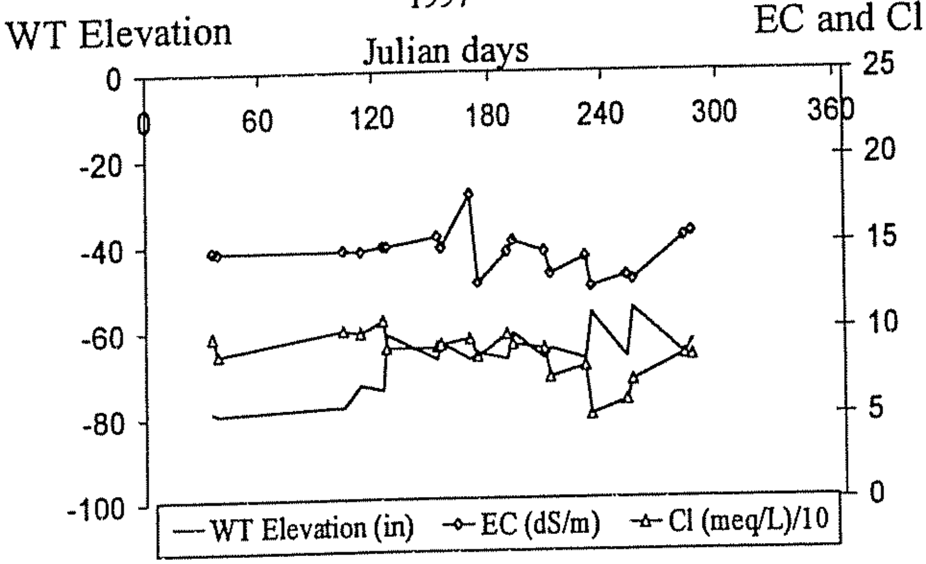


Figure 27. Water table elevation and salinity, Area 70 sudangrass field. 1998

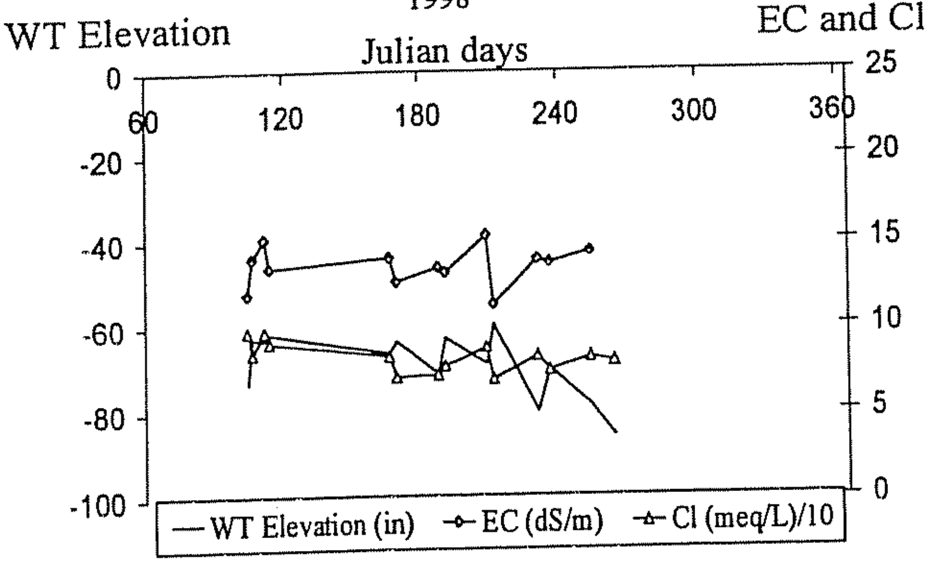


Figure 28. Alfalfa yield distribution along the field (dry tons/ac)

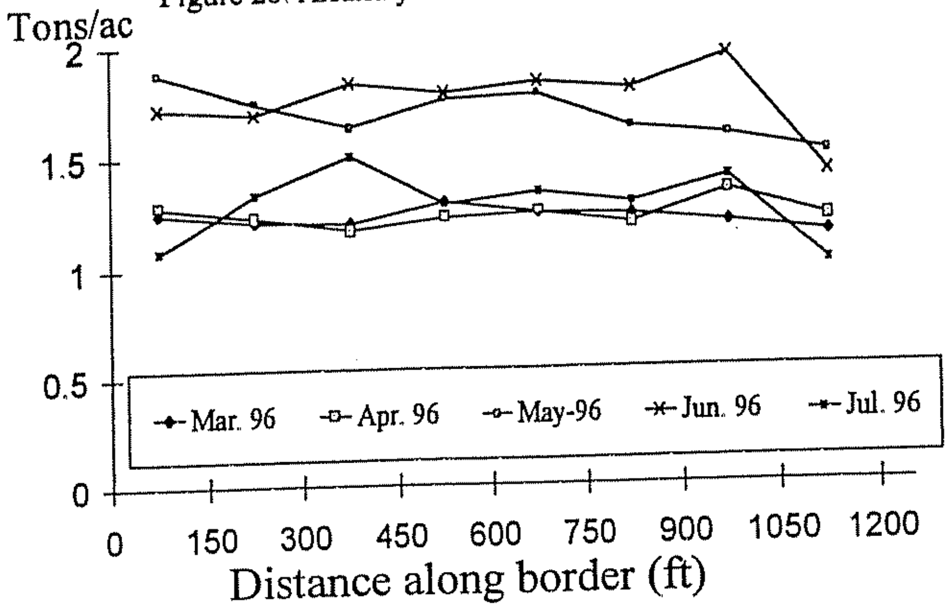
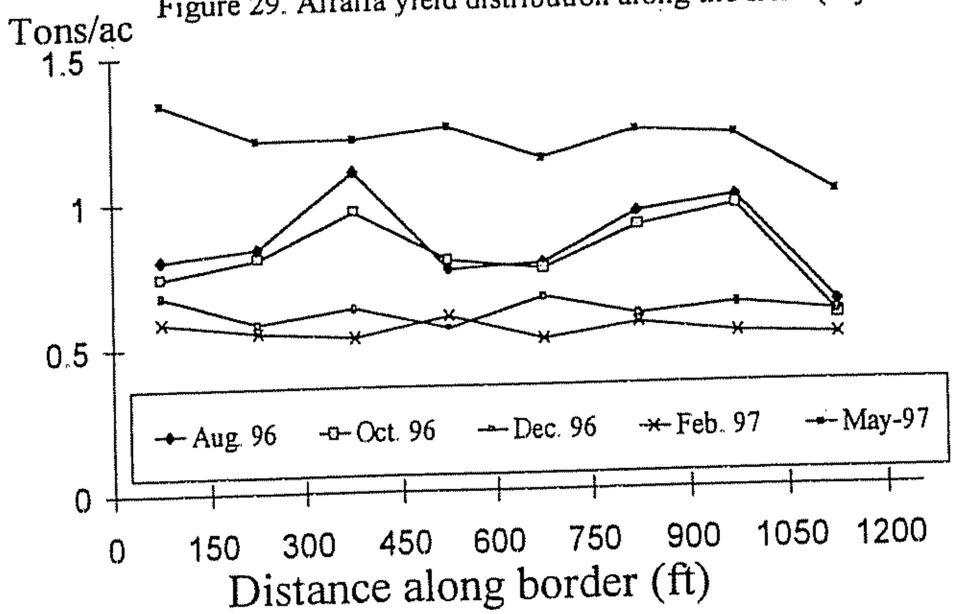


Figure 29. Alfalfa yield distribution along the field (dry tons/ac)



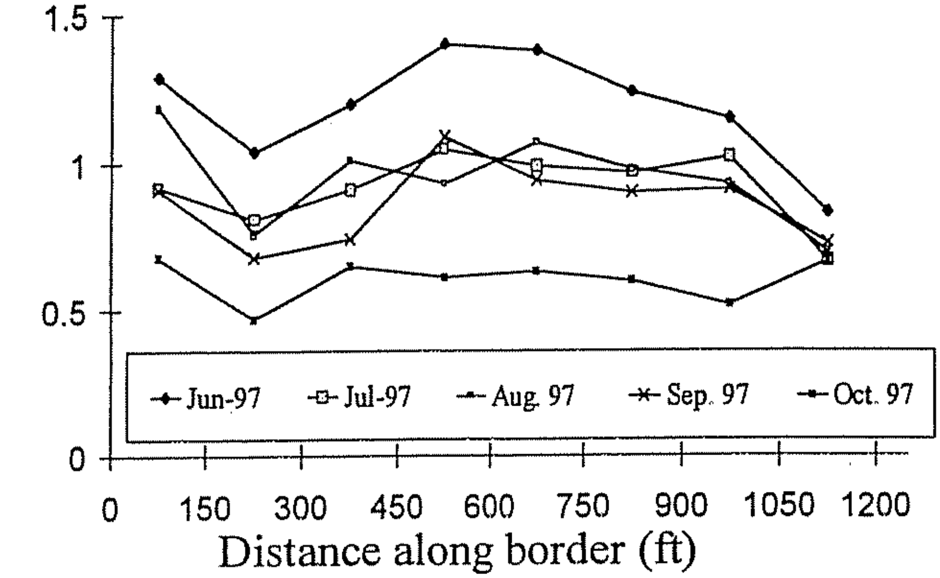


Figure 30. Alfalfa yield distribution along the field (dry tons/ac)

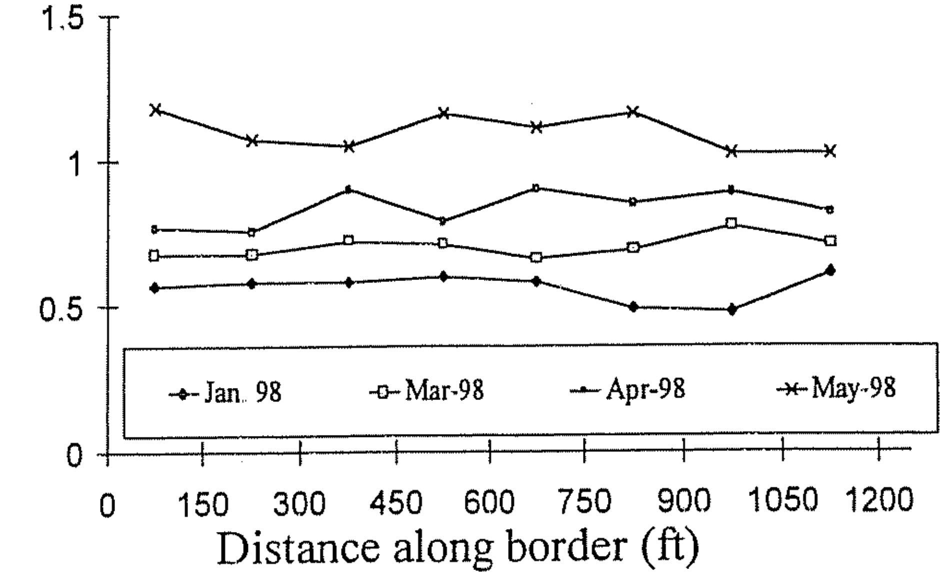


Figure 31. Alfalfa yield distribution along the field (dry tons/ac)

Figure 32. Alfalfa yield distribution along the field (dry tons/ac)

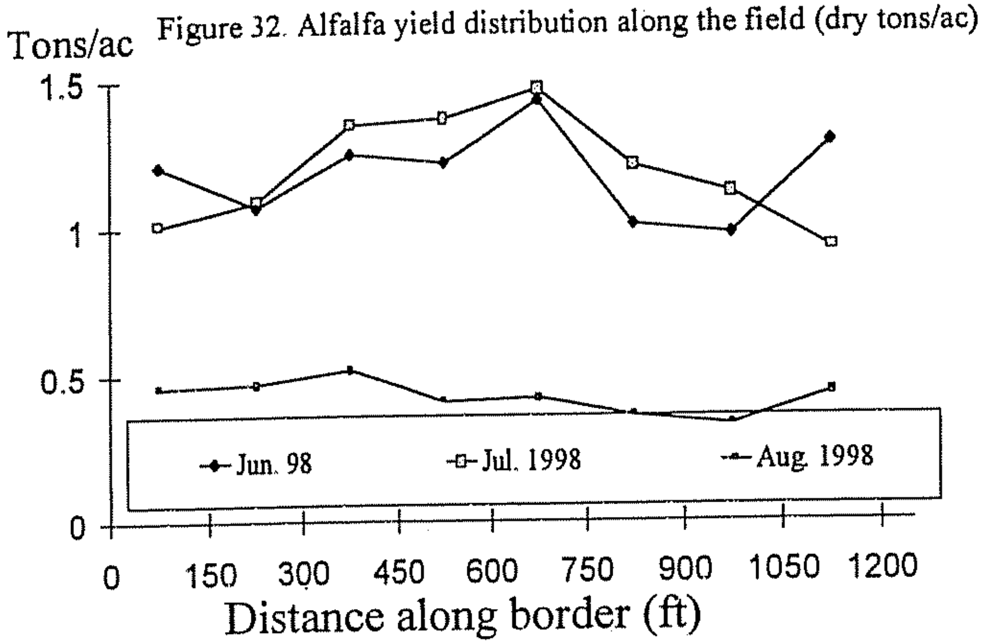


Figure 33. Alfalfa yield distribution along the field (dry tons/ac)

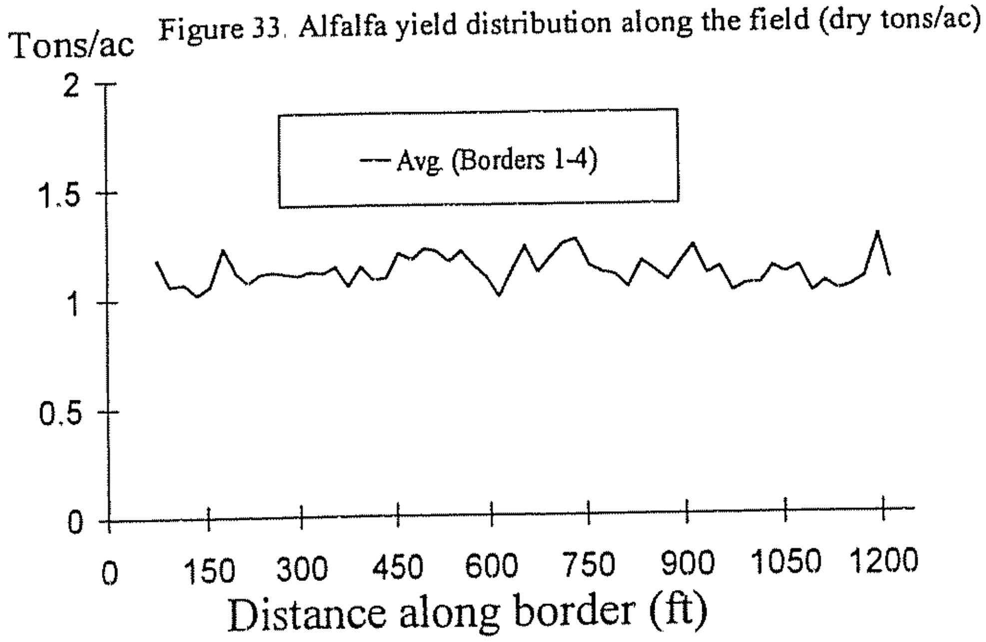


Figure 34. Alfalfa yield distribution along the field.

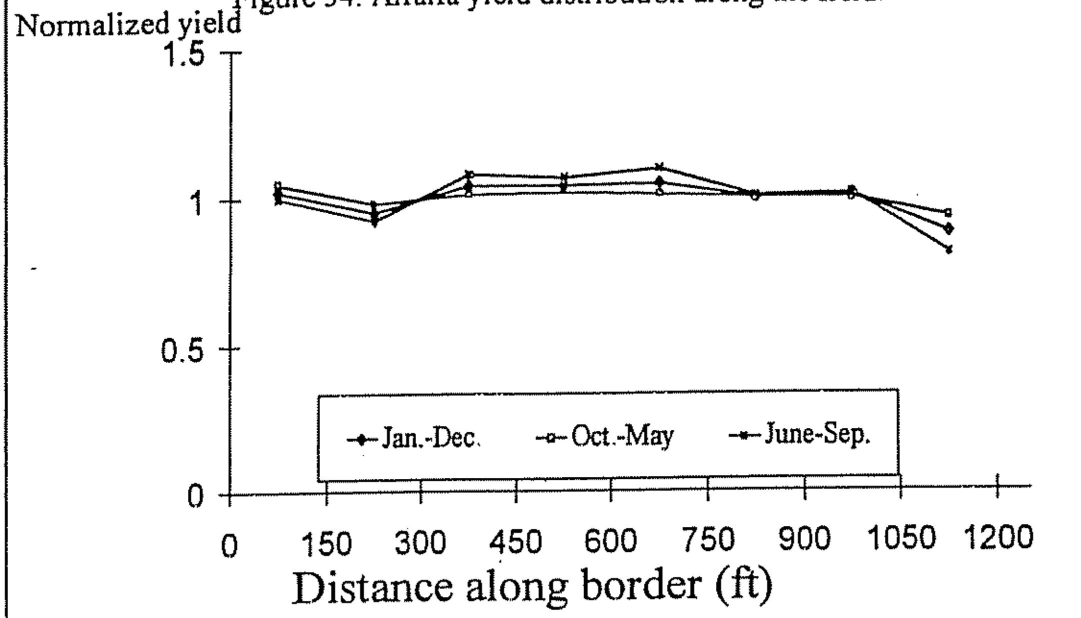


Figure 35. Corn dry mater distribution along the field (dry gm/section)

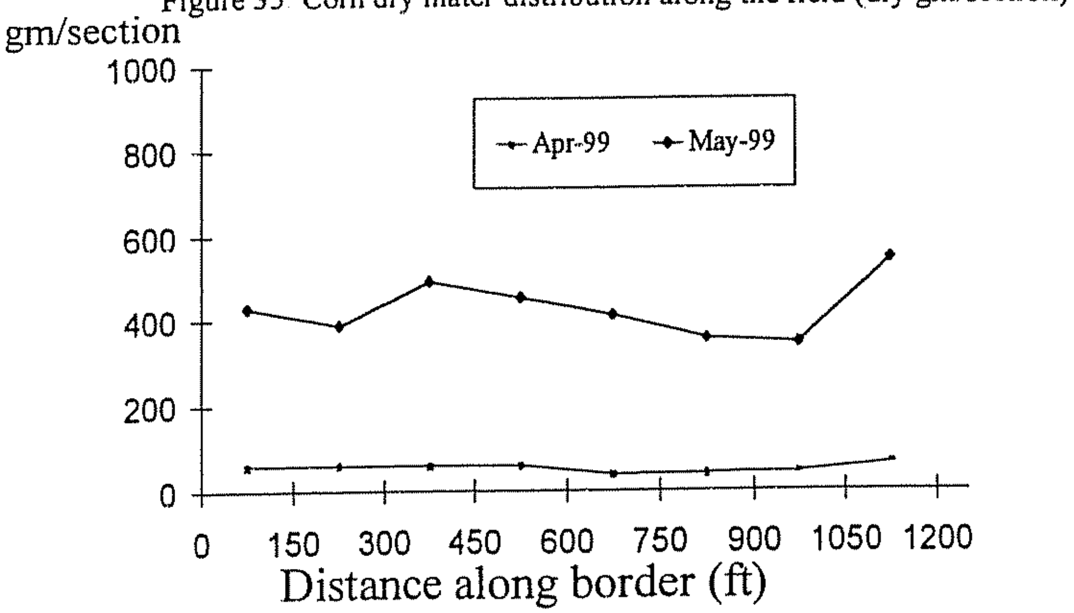


Figure 36. Alfalfa hay quality parameters (May 1997)

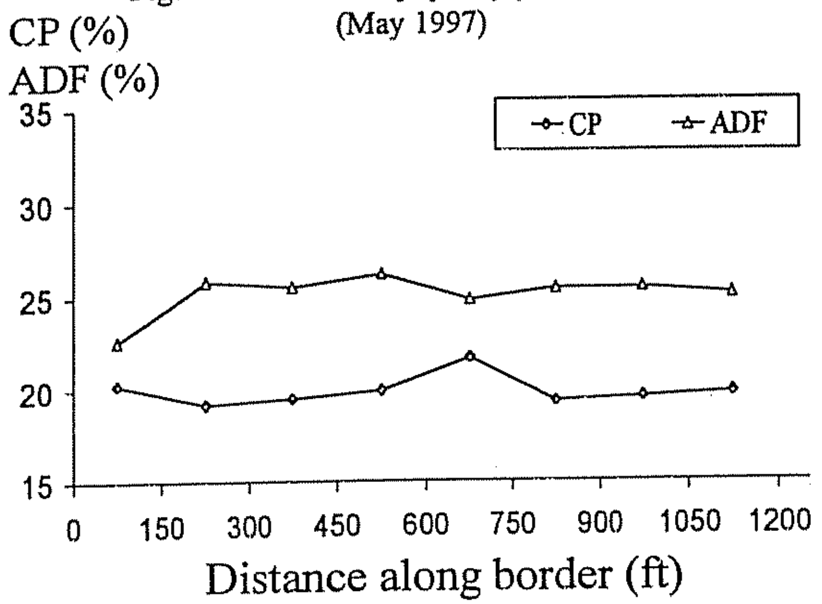


Figure 37. Average Soil Salinity Profiles Along Alfalfa field, November 1995

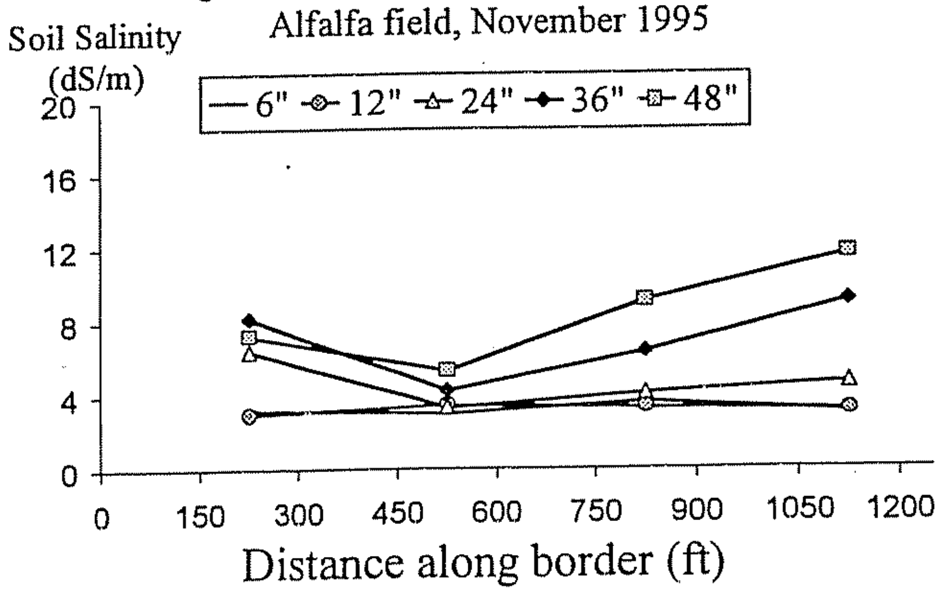


Figure 38. Average Soil Salinity Profiles Along Alfalfa field, January 1996

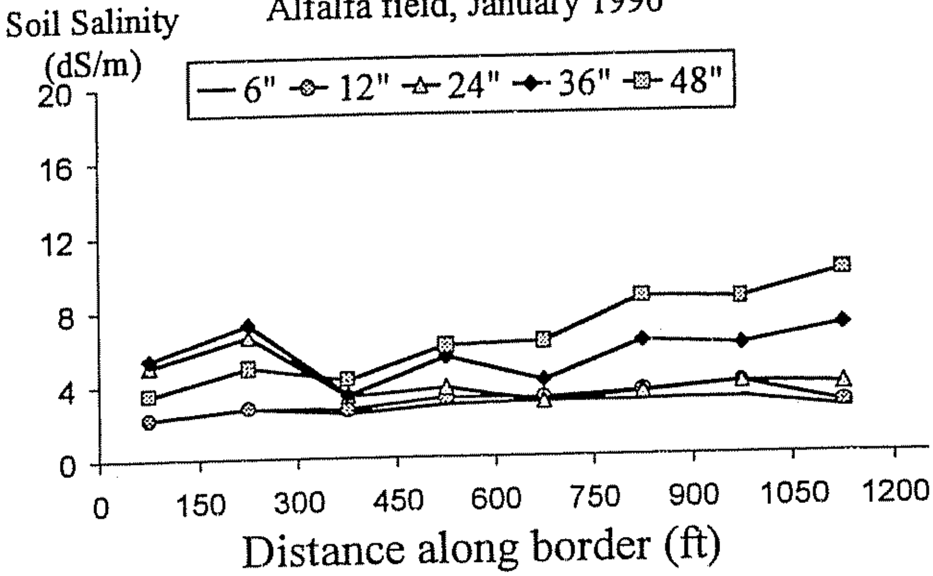


Figure 39. Average Soil Salinity Profiles Along Alfalfa field, November 1996

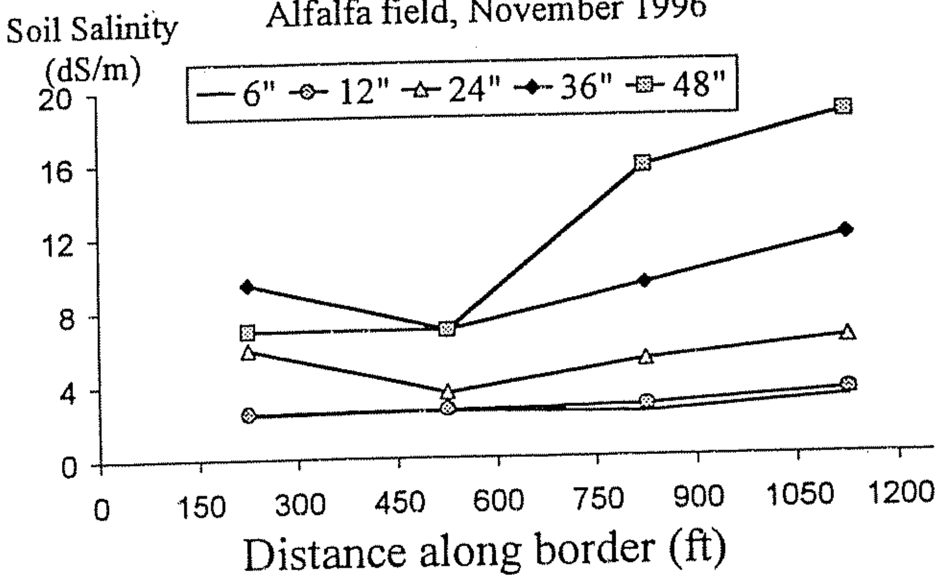


Figure 40. Average Soil Salinity Profiles Along Alfalfa field, March 1997

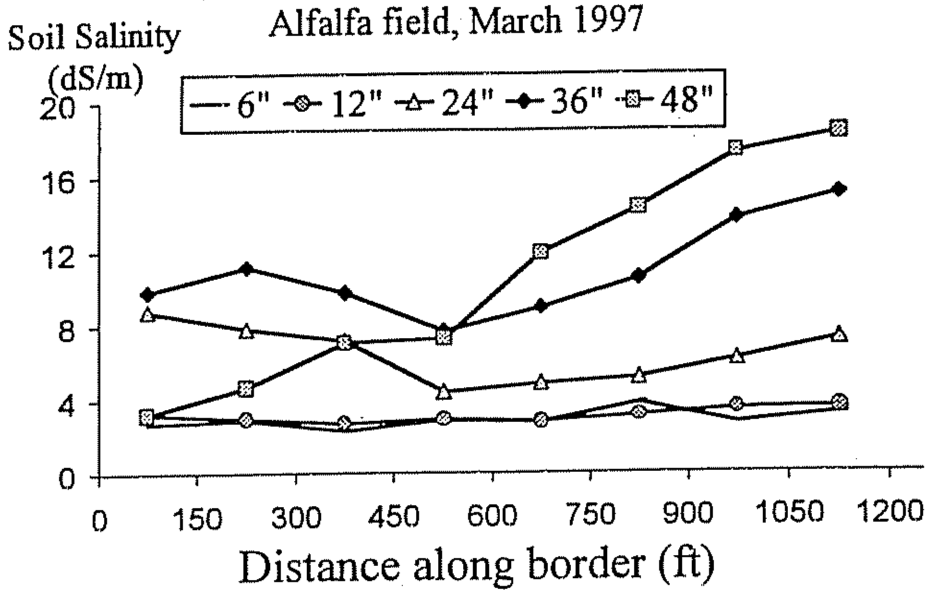


Figure 41. Average Soil Salinity Profiles Along Alfalfa field, October 1997

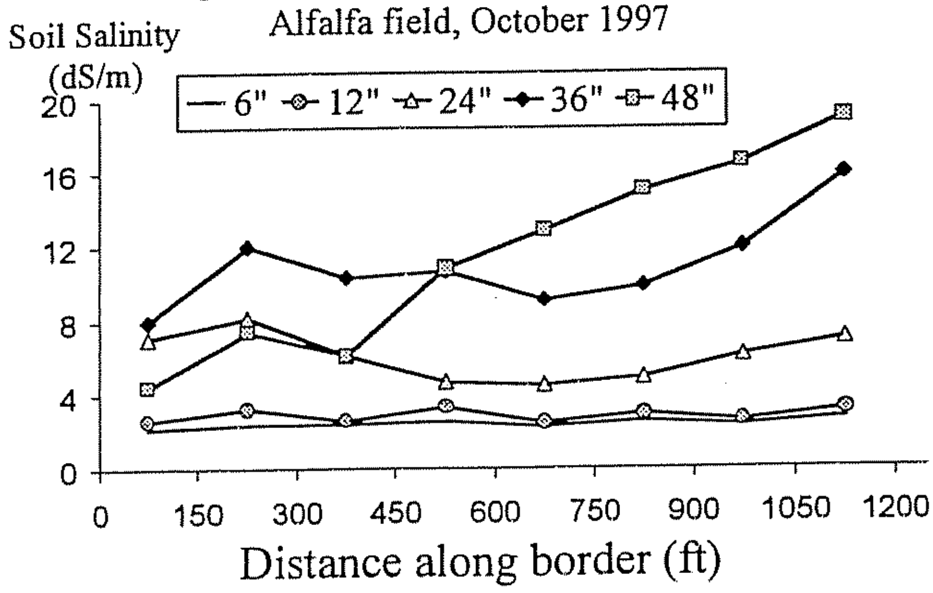


Figure 42. Average Soil Salinity Profiles Along Alfalfa field, August 1998

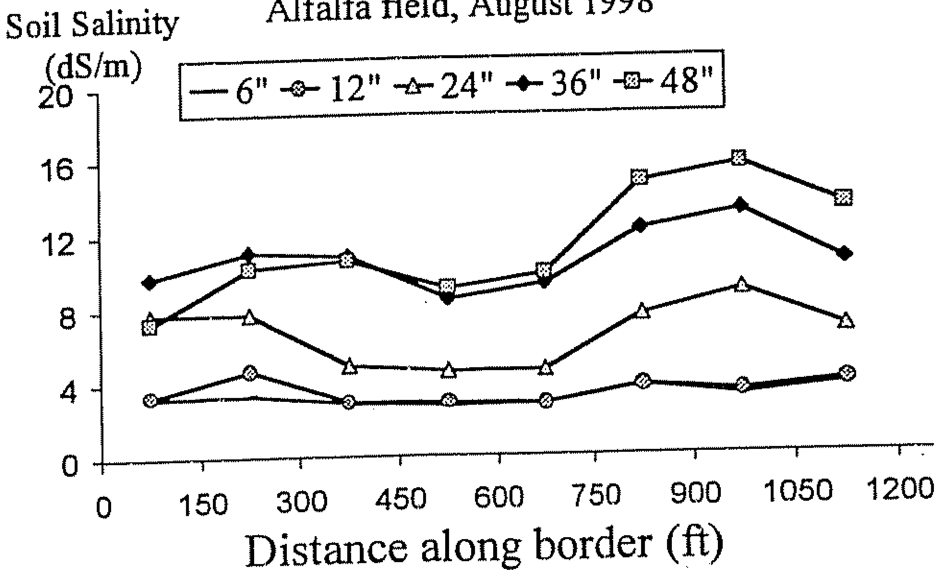


Figure 43. Average Soil Salinity Profiles Along Alfalfa field, November 1998

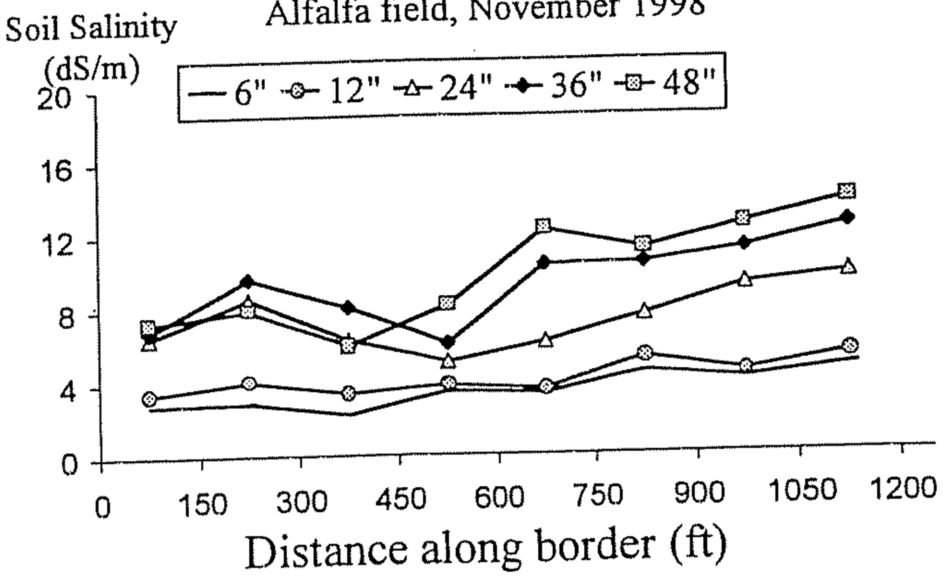


Figure 44. Average Soil Salinity Profiles Along Corn field, May 1999

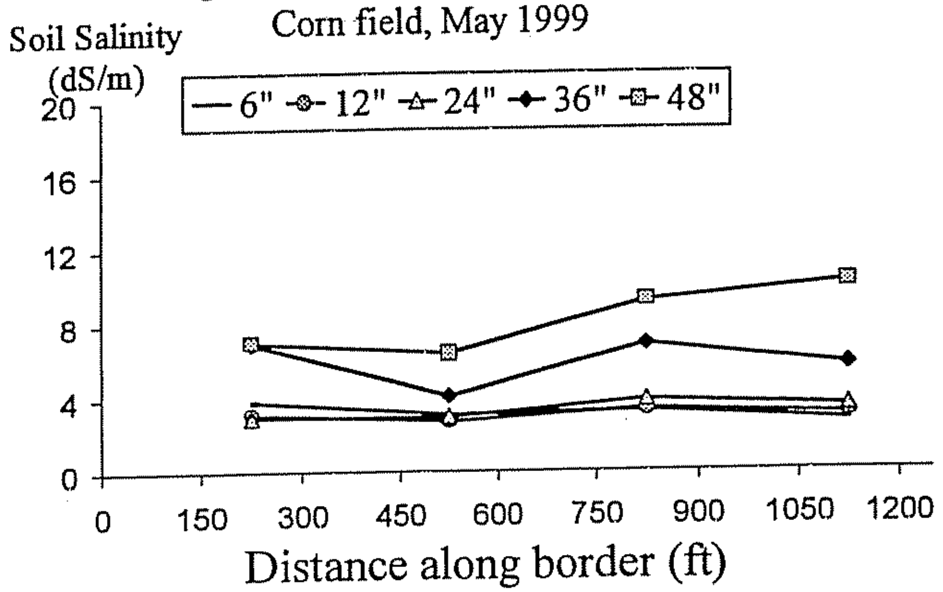
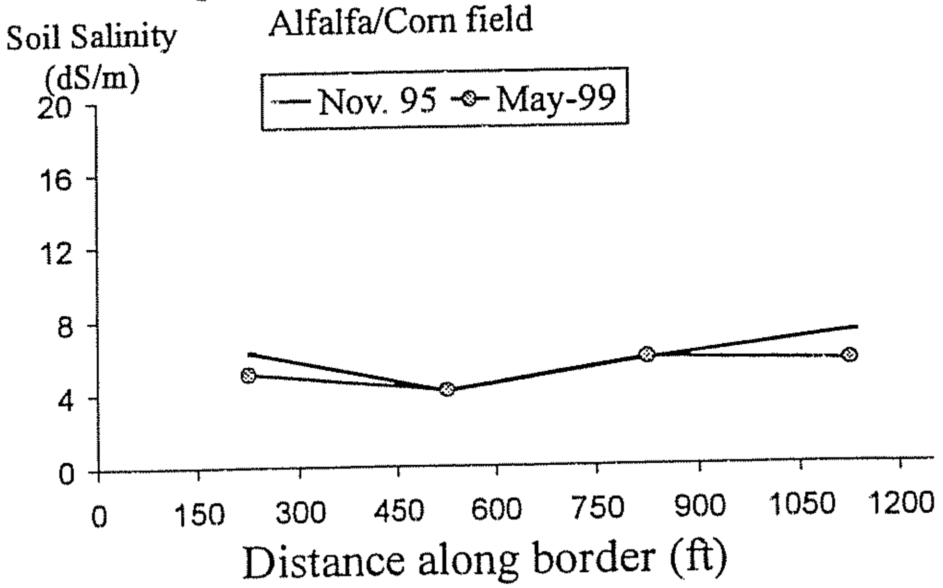
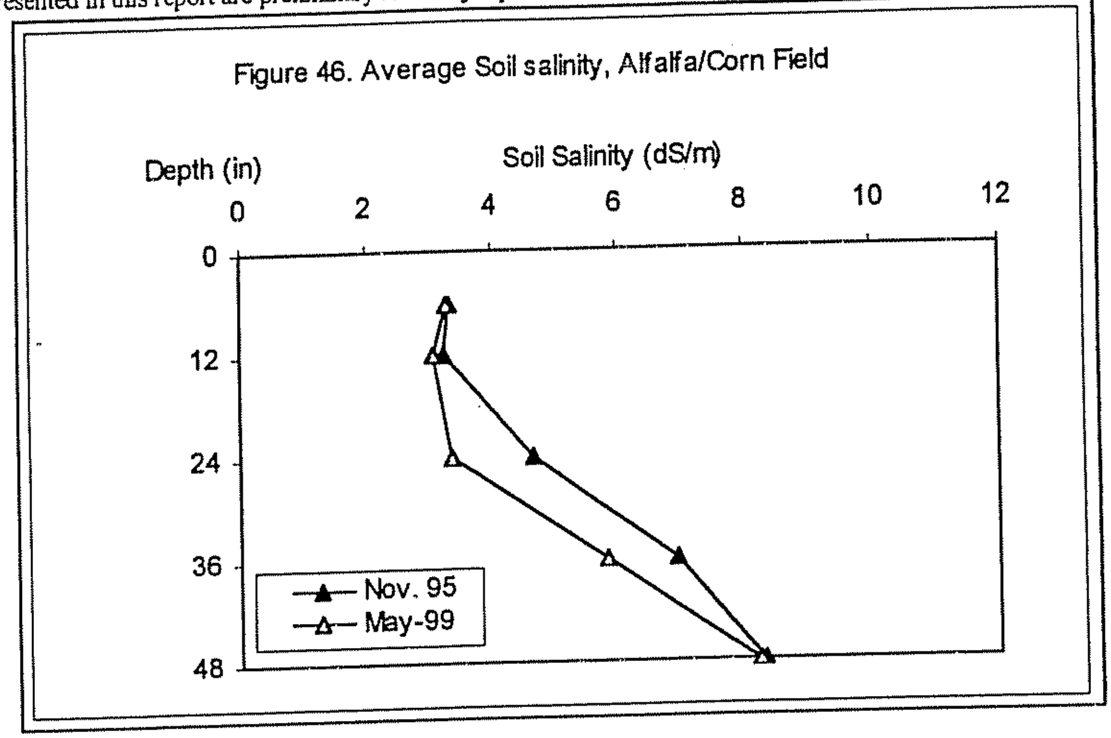


Figure 45. Average Soil Salinity Profiles Along Alfalfa/Corn field



DRAFT FOR DISCUSSION ONLY

Data presented in this report are preliminary *and not for publication* until authorized by the investigators – December 1999



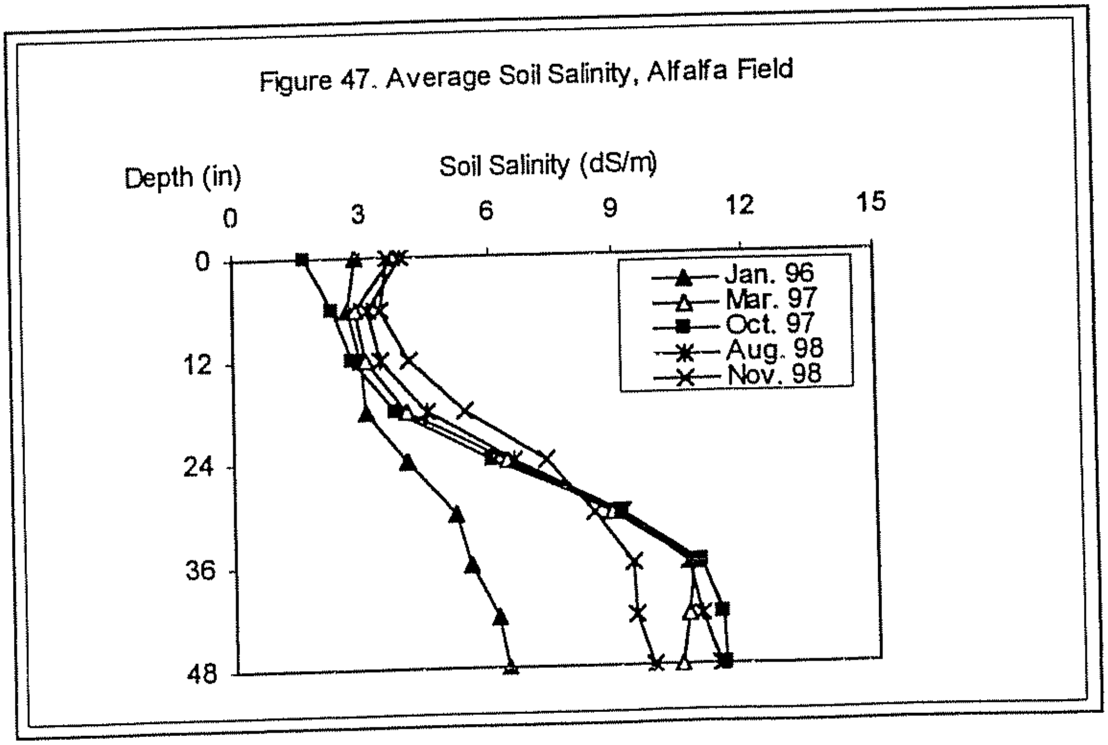


Figure 48. Average Cl Concentration, Alfalfa Field

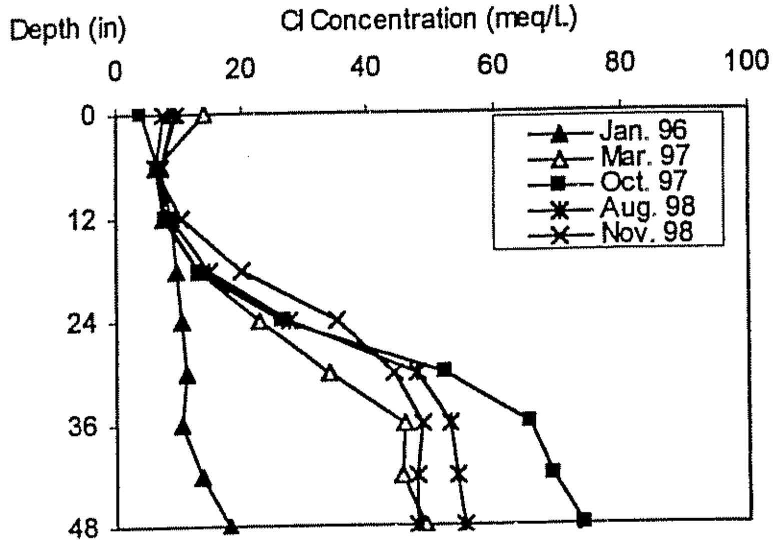
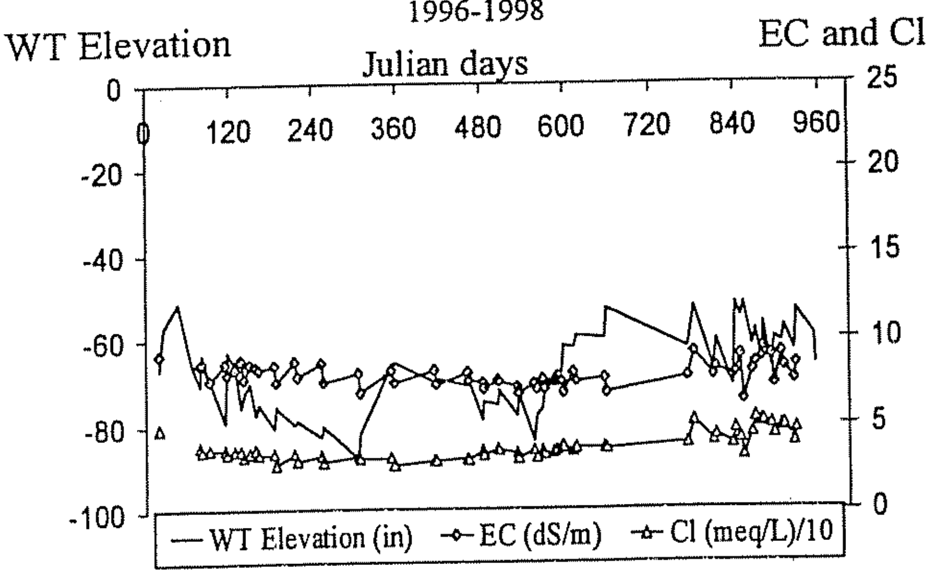
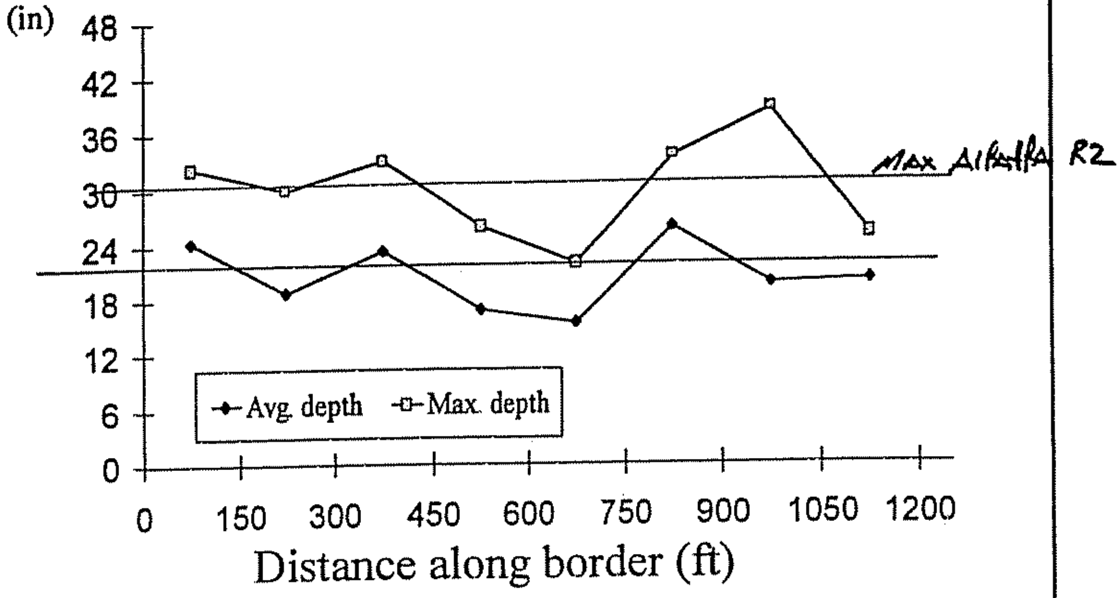


Figure 49. Water table elevation and salinity, Area 80 alfalfa field. 1996-1998



Root depth Figure 50. Average and maximum alfalfa root depth.



Inter-Office Memo

To Elston Grubaugh
From Steve Knell
Subject: Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley, Khaled Bali Paper, UC Cooperative Extension
c.c. John Eckhardt

I have reviewed the paper written by Khaled Bali, Farm Advisor at the UC Desert Research and Extension Center, U.C. California Cooperative Extension, entitled, Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley. I found the paper to be poorly lacking in substantive material to support many of the claims promoted in the conclusion. IID has commented previously on many of the reports prepared by Mr. Bali for this project. Likewise, IID and the farm community has continually objected to many of the overly zealous conclusions presented by Mr. Bali with little to no success in changing his views. I doubt commenting further is going to change this product, but for the record, my comments on the paper are as follows:

1. The reference in the Executive Summary that, "This report describes the development of a new method to minimize runoff. . ." is hardly accurate. The practice of under irrigating crops to extend water resources in areas where water is in short supply has been in existence for centuries around the world.

2. Section 4.1 Soil Type: All reference to soil 115 Glenbar silty clay loam should be changed to Imperial-Glenbar silty clay loam. This error also appears on page 33, second paragraph. The soil series should be accurately named, although the IID and the NRCS has continually maintained that the soil depicted as an Imperial-Glenbar in the study area is actually closer to a Holtville soil series.

   The Imperial-Glenbar soil does not contain a sand lens at the 60-inch depth, as was observed in test pits at the station in the test site area. For Mr. Bale to continually state that the soil in the study area is typical of heavy clay soils in the Valley is misleading and incorrect. The reference they use is Zimmerman (1981) on page 32 to substantiate this. If one looks in *Section 7 References* in the report, you see this reference is nothing more than an overlay of the SCS Soil Survey over the field station and the NRCS has maintained that the soil may have been wrongly mapped. Even the soil survey has an accuracy of +/- 10 acres

   Regardless, the soil survey states that Imperial-Glenbar is not well suited to growing alfalfa due to the heaving of the taproot from the soils shrink-swell action. The fact that the study site seems to grow alfalfa well is another indication that this soil is miss-diagnosed in the report

3. The report compares all data gathered in the study to "average values" of sudan and alfalfa in the Imperial Valley rather than to a scientific control plot. The lack of a control for comparison purposes is a serious flaw in the study.

4. Both test sites in the study (area 70 and 80) have soils with similar water holding capacities as is referenced in Table 11 on page 32. If the available water is 0.2 in/in for depths 0"-48" in both study sites and the average root zone for the alfalfa (reference Figure 50) is 30 inches, then by simple math, the available water to the crop is 0.2 in/in X 30 inches = 6 inches total. The study also lists the Kc values for sudan as 0.81 and for alfalfa as 0.84. Please reference *Table 14. Irrigation information- (sudangrass field)-1996*, the third column in the table is *ETo since previous irrigation*. We know that ETo X Kc = ETc. If you multiply the ETo listed in the tables by the Kc for sudan, you derive the ETc since the last irrigation. ETc is the amount of water the crop transpired since the last irrigation. The following table does that,

ETo since previous irrigation	Kc for sudan	ETc (crop water transpired since last irrigation)
5.04	0.84	4.3
7.57	0.84	6.4
11.51	0.84	9.7
7.87	0.84	6.6
8.43	0.84	7.1
7.4	0.84	6.2

Also see the footnote under Table 11, page 32 which states, *Allowable depletion: 50% for most crops, 50-65% for crops that are relatively insensitive to water stress*. Having determined the soil has only 6-inches of available water, then plant stress would appear at 65% of 6-inches or at 3.9 inches of moisture depletion. That being the case, if you look at the third column above you will see the depletion levels of the soil prior to irrigation on the sudan field used in the study. This represents moisture depletion levels of 72%, 106%, 162%, 110%, 118%, and 103%, and nowhere in the study is it referencing any plant stress, much less complete plant shutdown? This same number workup can be applied to the alfalfa study, with equally significant soil moisture depletions, and again no reference is made to plant stress or growth problems in the alfalfa.

With all of this staring at the reader, the conclusion of the study says that makeup water from the aquifer is only 11-18%. From the above, it looks like makeup water is in the range of 70-100%, and at times even greater.

If one looks at the Table 22 for the alfalfa field irrigation history, and knows that stress for alfalfa occurs at a moisture depletions of 65% of the soil's 6-inch water holding capacity (i.e. 3.9 inches), and you look down the third column (ETo (in) since previous irrigation), and multiplies those numbers by the crop Kc of 0.81, most all resultant values are in the wilting point range for alfalfa. Especially look at the dates 9-10-96 and 11-1-96 where ETo is 11.11 inches and 10.75 inches respectively. That is a moisture depletion of [(0.81X11.11)/6]X100=150%.

There just seems to be a lack of reality in this study, and that is probably the most frustrating thing to get across to Khaled.

There are numerous other issues on the study but all seem minor compared the major issues I've raised here. If questions, call.

Steve Knell

My docs/gen. Comments/khaled bali comments

400.02

IMPERIAL IRRIGATION DISTRICT

ANNUAL INVENTORY OF AREAS RECEIVING WATER

YEARS 1998, 1997, 1996

I. CROP SURVEY

GARDEN CROPS	ACRES 1998	1997	1996
ARTICHOKE	199	378	228
ARTICHOKE (SEED)	30	10	0
BEANS	23	203	355
BLACKEYED PEAS	0	314	0
BROCCOLI	9,589	6,480	6,311
BROCCOLI (SEED)	156	23	207
CABBAGE	1,126	961	710
CABBAGE (SEED)	0	20	0
CABBAGE, CHINESE	0	5	0
CARROTS	16.416	16,014	15.469
CARROTS (SEED)	0	5	138
CAULIFLOWER	3.313	2,553	2,776
CAULIFLOWER (SEED)	66	11	2
CELERY	65	204	109
CELERY (SEED)	12	32	0
CHICORY	0	0	6
CHINESE GRASS	0	0	10
COLLARDS	6	10	0
CUCUMBERS	18	0	19
EAR CORN	6,088	5,500	4,372
EGGPLANT	5	5	70
ENDIVE	25	55	0
ENDIVE (SEED)	0	0	150
FLOWERS	116	125	94
FLOWERS (SEED)	48	40	50
GARBANZO BEANS	51	1,034	1,211
GARLIC	104	165	437
HERBS, MIXED	2	17	13
HERBS, MIXED (SEED)	0	200	0
KALE	96	54	0
LETTUCE	14.752	15,971	16,299
LETTUCE (SEED)	58	20	0
LETTUCE, GREEN	108	33	70
LETTUCE, RED	0	0	100
LETTUCE, ROMAINE	1,505	1,505	600
LETTUCE, MIXED	2.681	2.663	2,230
MELONS			
CANTALOUPES, FALL	1,871	2.138	0
CANTALOUPES, SPRING	12.216	11,397	13,337
CRENSHAW, SPRING	0	15	0
HONEYDEW, FALL	406	180	316
HONEYDEW, SPRING	457	688	682
KAVA	140	20	0
MIXED, FALL	12	108	5
MIXED, SPRING	438	1.087	505
WATERMELONS	1.635	2,419	2,822
WATERMELONS (SEED)	0	1	0
MUSTARD	134	178	122
MUSTARD (SEED)	13	13	15
OKRA	30	91	96
OKRA (SEED)	0	44	0
ONIONS	9.757	10,176	13,324
ONIONS (SEED)	2,256	3,573	1,882
PARSLEY	0	2	0
PARSNIPS	44	42	0
PEAS (SEED)	0	7	7
PEPPERS, BELL	370	459	568
PEPPERS, HOT	29	56	39
POTATOES	2.622	2.784	2.538
RADISHES	155	37	146
RADISHES (SEED)	17	8	0
RAPINI	1.150	722	704
RHUBARB	0	0	10
RUTABAGAS	0	81	0
SPINACH	950	646	372
SPINACH, CHINESE	30	0	22
SQUASH	114	150	59
SQUASH (SEED)	33	9	0
SWEET BASIL	9	150	120
SWISS CHARD	5	40	0
TOMATOES, FALL	0	22	0
TOMATOES, SPRING	655	840	2,022
TURNIPS	141	377	193
VEGETABLES, MIXED	1,711	1,761	803
VEGETABLES, MIXED (SEED)	0	15	13
WATERLILIES	30	84	110
TOTAL GARDEN CROPS	94,088	95,030	93,868

FIELD CROPS	ACRES 1998	1997	1996
ALFALFA, FLAT	120,675	117,368	113,429
ALFALFA, ROW	53.688	43.594	39,405
ALFALFA (SEED)	19,781	14.248	13.238
ALICIA GRASS	1	1	1
BAMBOO	94	81	15
BARLEY	337	91	58
BERMUDA GRASS	31,774	24,301	20,952
BERMUDA GRASS (SEED)	21,865	20,613	22.636
BUFFLE GRASS	37	112	169
COTTON	4,640	3,970	4,601
DUNALIELLA	25	25	25
FIELD CORN	579	1,683	453
FLAX	12	4	8
GRASS, MIXED	74	84	29
HEMP	94	0	0
KENAF	65	3	16
KLIEN GRASS	1.623	567	452
LEMON GRASS	5	5	5
OATS	2,411	1,753	1,267
RAPE	5.098	778	773
RED BEETS	10	30	23
RYE GRASS	4,968	4,600	2.978
RYE GRASS (SEED)	0	0	37
SESBANIA	0	322	120
SORGHUM GRAIN	40	255	2,536
SORGHUM SILAGE	193	376	100
SPIRULINA ALGAE	70	70	70
SUDAN GRASS	66,568	83,562	81,896
SUDAN GRASS (SEED)	391	310	300
SUGAR BEETS	34,258	39,327	33.980
SUGAR CANE	80	80	79
WHEAT	80,184	90,005	106,513
TOTAL FIELD CROPS	449,640	448,238	446,164

PERMANENT CROPS	ACRES 1998	1997	1996
ASPARAGUS	5,574	5,337	4,919
CITRUS			
GRAPEFRUIT	1.337	1,194	1,200
LEMONS	1,914	1,834	1.161
MIXED	944	278	78
ORANGES	840	780	667
TANGERINES	692	662	662
DATES	98	82	82
DUCK PONDS (FEED)	8.979	8,837	8,798
EUCALYPTUS	14	14	14
FISH FARMS	1,293	1,263	1,173
FRUIT, MIXED	10	10	10
GUAR BEANS	153	104	276
JOJOBA	2	202	400
MANGOS	125	150	150
NURSERY	30	24	24
ORNAMENTAL TREES	15	15	5
PALMS	78	78	84
PASTURE, PERMANENT	684	722	696
PEACHES	7	2	2
PECANS	17	17	27
TOTAL PERMANENT CROPS	22,806	21,605	20,428
TOTAL ACRES OF CROPS	566,534	564,873	560,460

NOTE: CROPS ARE LISTED FOR THE YEAR IN WHICH THEY ARE PREDOMINATELY HARVESTED.

SUMMARY

	1998		1997		1996	
Number of Farm Accounts	6,290		6,299		6,289	
Number of Owner-Operated Farm Accounts	2,760	43.9%	2,702	42.9%	2,743	43.6%
Number of Tenant-Operated Farm Accounts	3,530	56.1%	3,597	57.1%	3,546	56.4%
Average Acreage of Farm Accounts	76.20		76.11		76.36	

II SUMMARY OF AREA SERVED

	ACRES		
	1998	1997	1996
FIELD CROPS	449,640	448,238	446,164
GARDEN CROPS	94,088	95,030	93,868
PERMANENT CROPS	22,806	21,605	20,428
TOTAL ACRES OF CROPS	566,534	564,873	560,460
TOTAL DUPLICATE CROPS	105,473	104,167	99,848
TOTAL NET ACRES IN CROPS	461,061	460,706	460,612
AREA BEING RECLAIMED: LEACHED	190	263	503
NET AREA IRRIGATED	461,251	460,969	461,115
AREA FARMABLE BUT NOT FARMED DURING YEAR (FALLOWED LAND)	18,076	18,448	19,136
TOTAL AREA FARMABLE	479,327	479,417	480,251
AREA OF FARMS IN HOMES, FEED LOTS, CORRALS, COTTON GINS, EXPERIMENTAL FARMS, AND INDUSTRIAL AREAS	16,019	15,959	15,859
AREA IN CITES, TOWNS, AIRPORTS, CEMETERIES, FAIRGROUNDS, GOLF COURSES, RECREATIONAL, PARKS, LAKES & RURAL SCHOOLS	26,013	26,013	25,504
TOTAL AREA RECEIVING WATER	521,359	521,389	521,614
AREA IN DRAINS, CANALS, RESERVOIRS, RIVERS, RAILROADS, AND ROADS	73,650	73,620	73,395
AREA BELOW -230 SALTON SEA RESERVE BOUNDARY & AREA COVERED BY SALTON SEA, LESS AREA RECEIVING WATER	40,150	40,150	40,150
AREA IN IMPERIAL UNIT NOT ENTITLED TO WATER	63,933	63,933	63,933
UNDEVELOPED AREA OF IMPERIAL, WEST MESA, EAST MESA, AND PILOT KNOB UNITS	277,629	277,629	277,629
TOTAL ACREAGE INCLUDED - ALL UNITS	976,721	976,721	976,721
* ACREAGE NOT INCLUDED - ALL UNITS	84,916	84,916	84,916
TOTAL GROSS ACREAGE WITHIN DISTRICT BOUNDARIES	1,061,637	1,061,637	1,061,637

IMPERIAL IRRIGATION DISTRICT

JR Eckhardt

JOHN R. ECKHARDT
Asst. General Manager
Water Department

* Acreage within District boundaries that is not included in District.